NAS5-23434
Mod 7.
Systematics General

# FREQUENCY BAND JUSTIFICATIONS FOR PASSIVE SENSORS

## 10.0 to 385 GHz

## Chapter II

**December 1976**

(NASA-CR-155532) FREQUENCY BAND JUSTIFICATIONS FOR PASSIVE SENSORS 10.0 TO 385 GHz, CHAPTER 2 (Systematics General Corp., McLean, Va.) 301 p HC A14/MF A01 CSCL 17B G3/32

N78-15329

Unclas
58014

NASA

National Aeronautics and Space Administration

Washington, D.C. 20546

# FREQUENCY BAND JUSTIFICATIONS FOR PASSIVE SENSORS

## 10.0 to 385 GHz

## Chapter II

**December 1976**

National Aeronautics and Space Administration

Washington, D.C. 20546

## PREFACE

This document presents the frequency allocation requirements for passive sensors utilized in the Earth Exploration Satellite and the Space Research Services. The document is organized into Chapters I and II, Parts A and B.

Chapter I, Part A presents the applications and, in some cases, potential benefits which are applicable to various microwave remote measurements. Since measurements are required simultaneously in multiple frequency bands to adequately determine values of some phenomena, these relationships between frequency bands are presented. The various measurement accuracies, dynamic range, resolutions and frequency needs are also discussed.

Chapter I, Part B presents a band-by-band summary of requirements, unique aspects and sharing analyses of the required frequency bands for passive sensors.

Chapter II, Part A discusses sensitivity requirements of the various measurements and microwave radiometry techniques while Part B provides the detailed band-by-band sharing analyses.

In addition, Appendices I-IV, describe the analytical techniques applied to the detailed sharing analyses. Appendix V, presents a bibliography of publications pertinent to the scientific justification of the frequency requirements for passive microwave remote sensing.

TABLE OF CONTENTS

ORIGINAL PAGE IS OF POOR QUALITY

## CHAPTER I



PRECEDING PAGE BLANK NOT FILMED

TABLE OF CONTENTS (cont.)

CHAPTER II

## LIST OF FIGURES

# CHAPTER II

## PART A

## MICROWAVE RADIOMETERY

MICROWAVE RADIOMETRY

Energy at microwave frequencies is emitted and absorbed by the surface of the earth and the atmosphere above the surface. The transmission properties of the absorbing atmosphere vary as a function of frequency as shown in Figure 1. This figure depicts calculated one way zenith (90° elevation angle) attenuation values for oxygen and water vapor.[1]. The calculations are for a path between the surface and a satellite. These calculations reveal frequency bands for which the atmosphere is effectively opaque and others for which the atmosphere is nearly transparent. The regions or windows that are nearly transparent may be used to sense surface phenomena; the regions that are opaque are used to sense the top of the atmosphere.

The power received by a radiometer on a satellite looking down at the earth may be calculated from the equations of radiative transfer[1,2]. For a nonscattering medium,

$$T_A(\nu) = \frac{P(\nu)}{\kappa B} = \frac{1}{4\pi} \int_0^{4\pi} G(\Omega) \left[ T_\circ(\nu) e^{-\tau(L)} + \int_0^L T(s) \beta(s) e^{-\tau(s)} ds \right] d\Omega \qquad (1)$$

where $T_A$ = antenna temperature

$P$ = received power

$\nu$ = center frequency

$B$ = receiver bandwidth

$\kappa$ = Boltzmann's constant

$G$ = antenna gain

$\Omega$ = solid angle about the antenna

$T_\circ$ = surface brightness temperature (emission plus scattering)

$\tau$ = optical depth

$\beta$ = absorption coefficient

$L$ = path length from satellite to ground

$s$ = position along the path

and $T(s)$ = atmospheric temperature at point s along the path

ORIGINAL PAGE IS OF POOR QUALITY

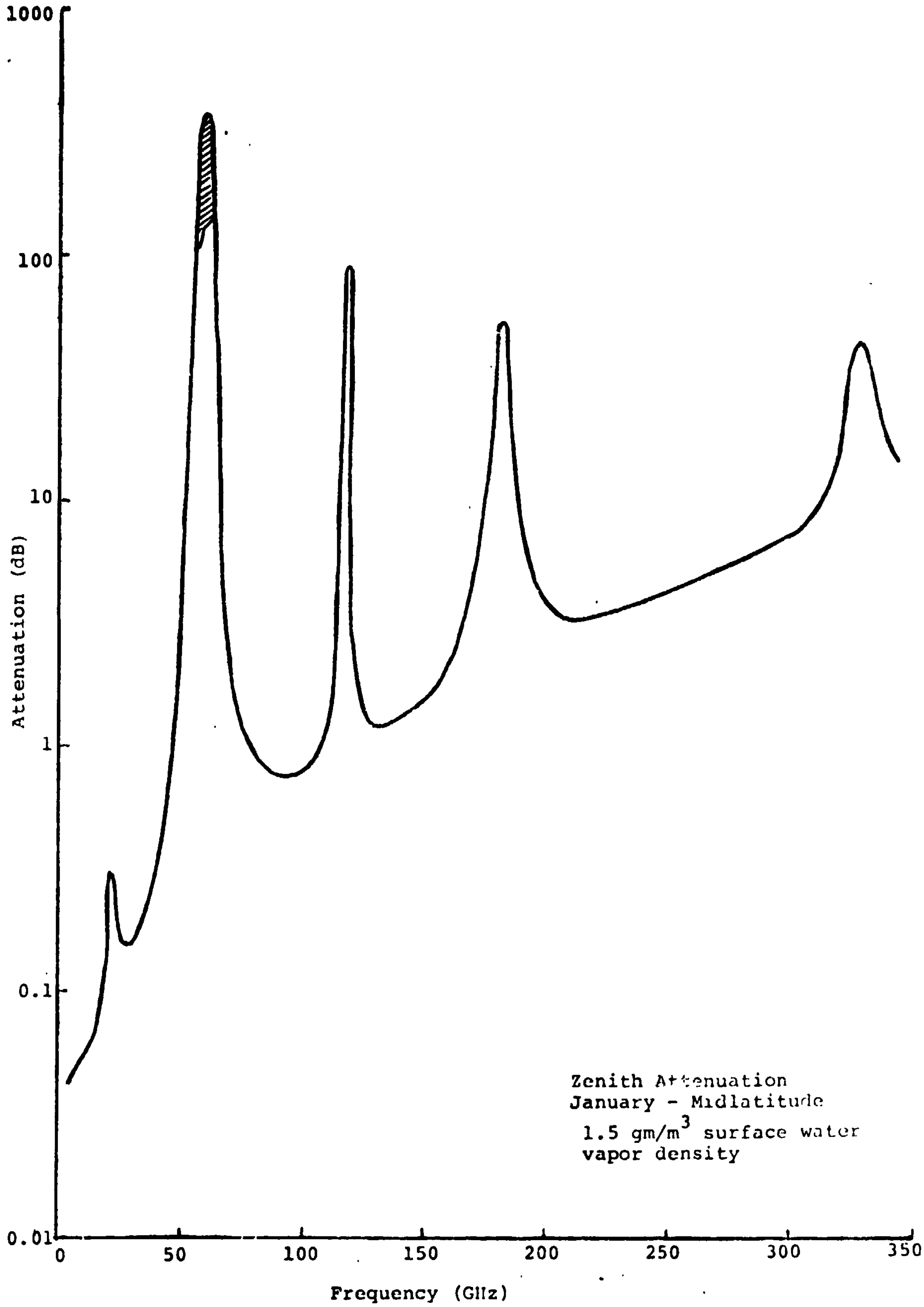



Figure 1. Zenith Attenuation vs. Frequency

The optical depth is simply related to the attenuation as

$$\tau(s) = \int_0^s \beta(x)dx = \int_0^s \left(\frac{a(x)}{4.34}\right)dx = \frac{A(s)}{4.34} \tag{2}$$

where A = attenuation (one way)
and a = specific attenuation.

Equations (1) and (2) display the essential features of remote sensing using microwave frequencies. The surface brightness temperature, the atmospheric temperature at points, s, along the path and the absorption coefficients are unknowns to be determined from measurements of the antenna temperature, $T_A$. The surface brightness temperature and the absorption coefficients in turn depend on the physical properties of the surface or atmosphere that are to be sensed. A single observation at a single frequency cannot be used to estimate a single physical parameter. Observations must be made simultaneously at a number of frequencies and combined with models for the frequency dependence and physical parameter dependence of the surface brightness temperature and of the absorption coefficient before the integral equation, equation (1), may be solved.

The equation may be simplified for application at frequencies in the atmospheric windows where the attenuation is less than 1 dB. For an antenna system with a narrow beam and for an absorber at a constant temperature, $T_s$ the equation reduces to

$$T_A \approx T_o \ell + T_s(1-\ell)$$

$$\ell = \int_0^L \frac{a(x)}{4.34}\, dx = \frac{A}{4.34}$$

This result shows that even in the windows, the effect of the atmosphere above the surface must be considered.

## Atmospheric Absorption

The attenuation does not occur within a single atmospheric layer of constant temperature. Figure 2 displays the variation

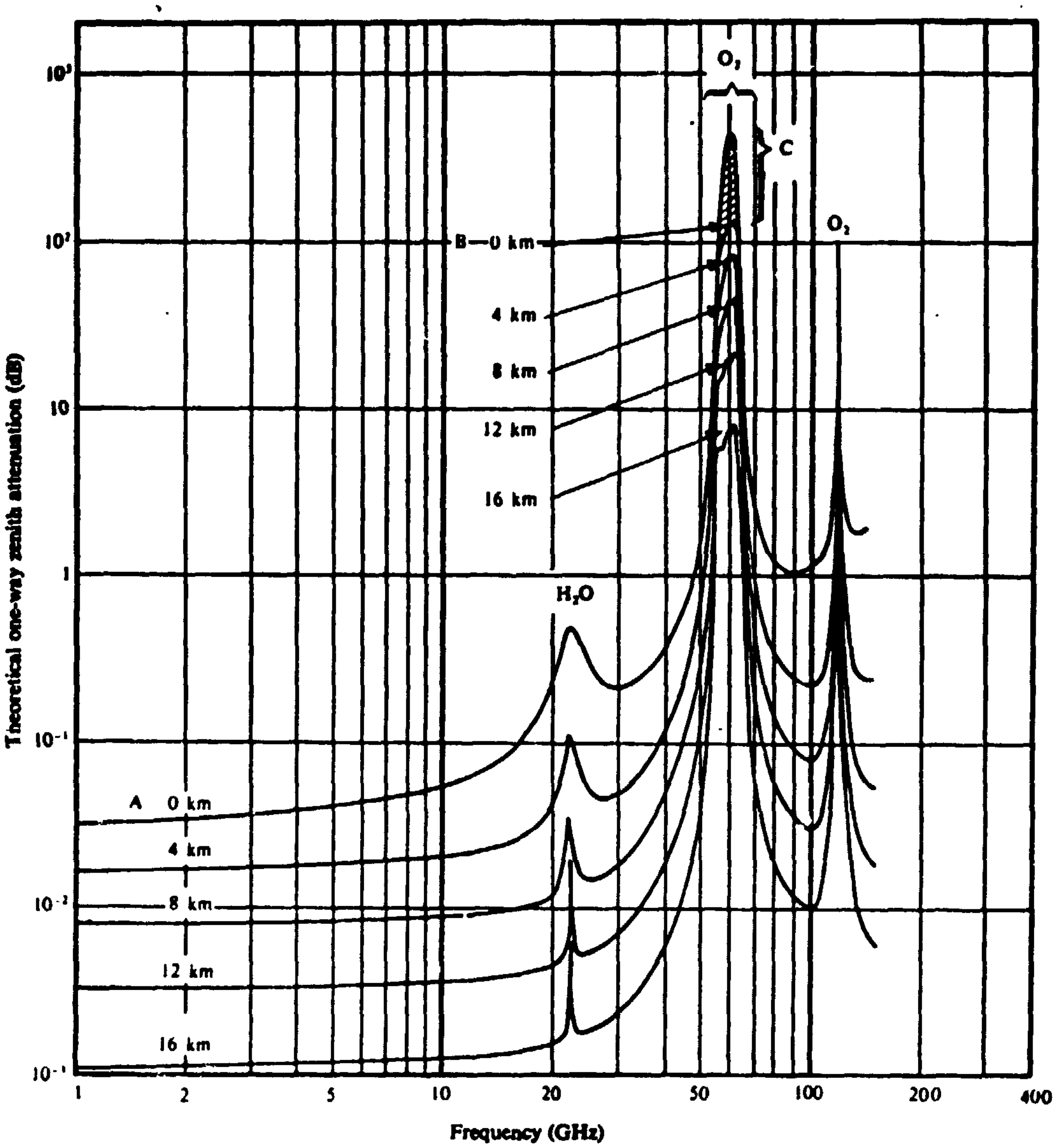



Figure 2. Theoretical vertical one-way attenuation from specified height to top of the atmosphere for a moderate humid atmosphere (7.5 $g/m^3$ at the surface).

A: Starting heights (km)
B: Minimum values for paths starting at indicated heights (km)
C: Range of values for the path from the surface to 80 km

of attenuation with frequency and height Equation 1 indicates that the measured antenna temperature depends most upon the temperature in the region along the path where the attenuation (total to the satellite) is less than 10 dB and little on temperatures in regions where the attenuation is very small or the total attenuation to the satellite is large. The temperature values can be sensed at different heights or distances along the path by selecting frequencies near the edges of the opaque regions with different attenuations which provide different weighting functions or multipliers of $T_{(s)}$ in equation (1). The broad opaque region between 50 and 70 GHz is composed of a number of narrow absorption (opaque) lines and observations may be made either at the edges of the complex of lines or in the valleys between the lines. The range of attenuation values - peak to valley for the complex of lines are indicated as shaded areas on Figs. 1 and 2.

A number of different frequencies may be chosen to provide a reasonable set of weighting functions for atmospheric temperature and water vapor profile measurements. Sample calculations for a set of frequencies in the oxygen line complex[3] are given in Figure 3 and for water vapor[4] in Figure 4. Calculations for the channels corresponding to the lowest five frequencies on Figure 3 performed using a statistical procedure for inverting equation (1)[4] show that for a 0.3°K radiometer sensitivity the expected rms uncertainty in the estimated temperatures is less than 2°C for heights above 1 km at midlatitudes over the ocean.

Clouds and rain can provide additional attenuation when they occur along the path. Figures 5 and 6 depict the frequency variation of attenuation due to liquid water and ice in precipitation. These curves show that both rain and clouds may be sensed in the atmospheric windows between 5 and 150 GHz. Multiple observations over a wide frequency range are required to separate rain from cloud and to separate these effects from surface emission[4].

The rain and cloud droplets scatter a part of the energy

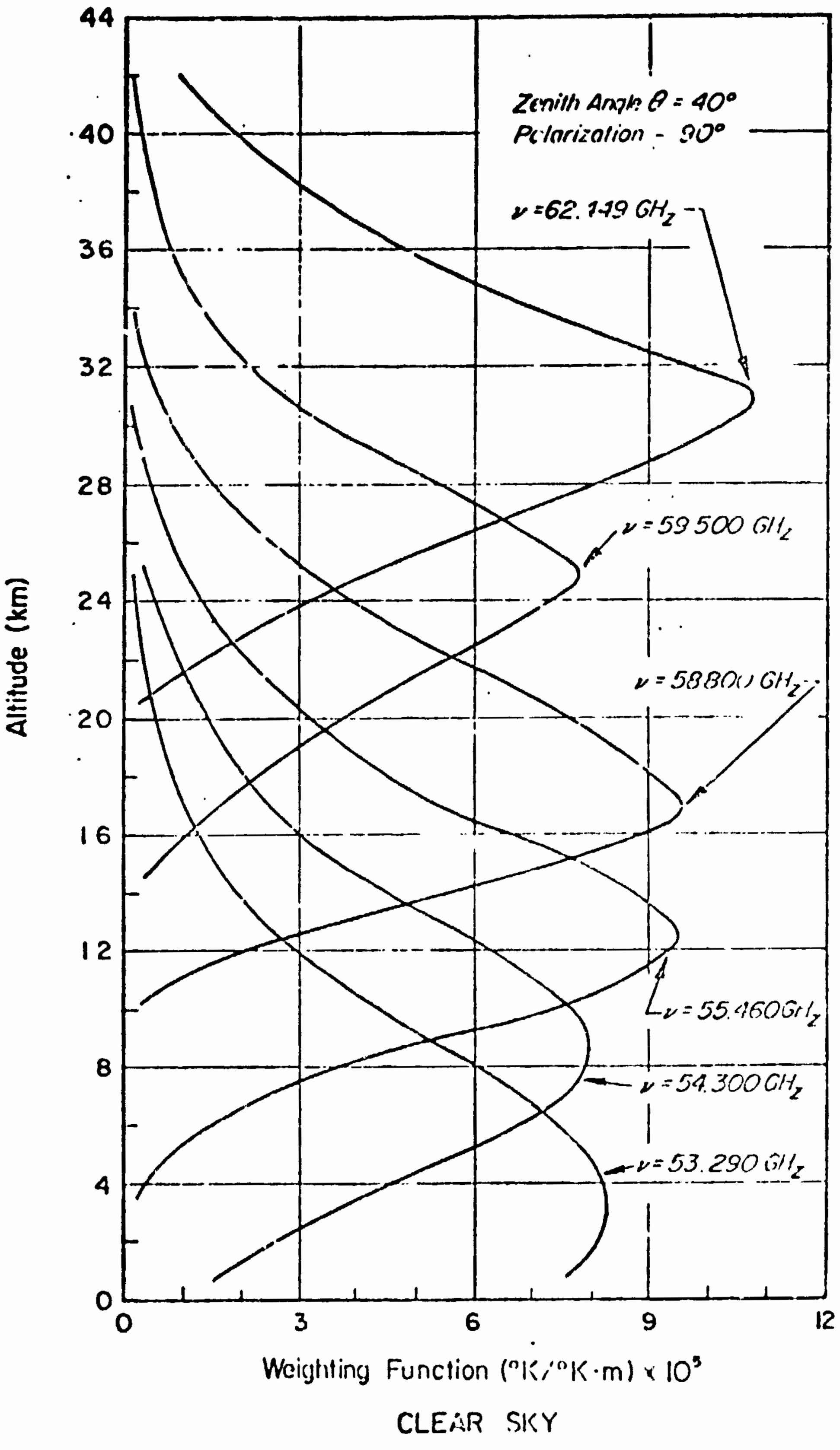



Figure 3. Temperature Weighting Functions

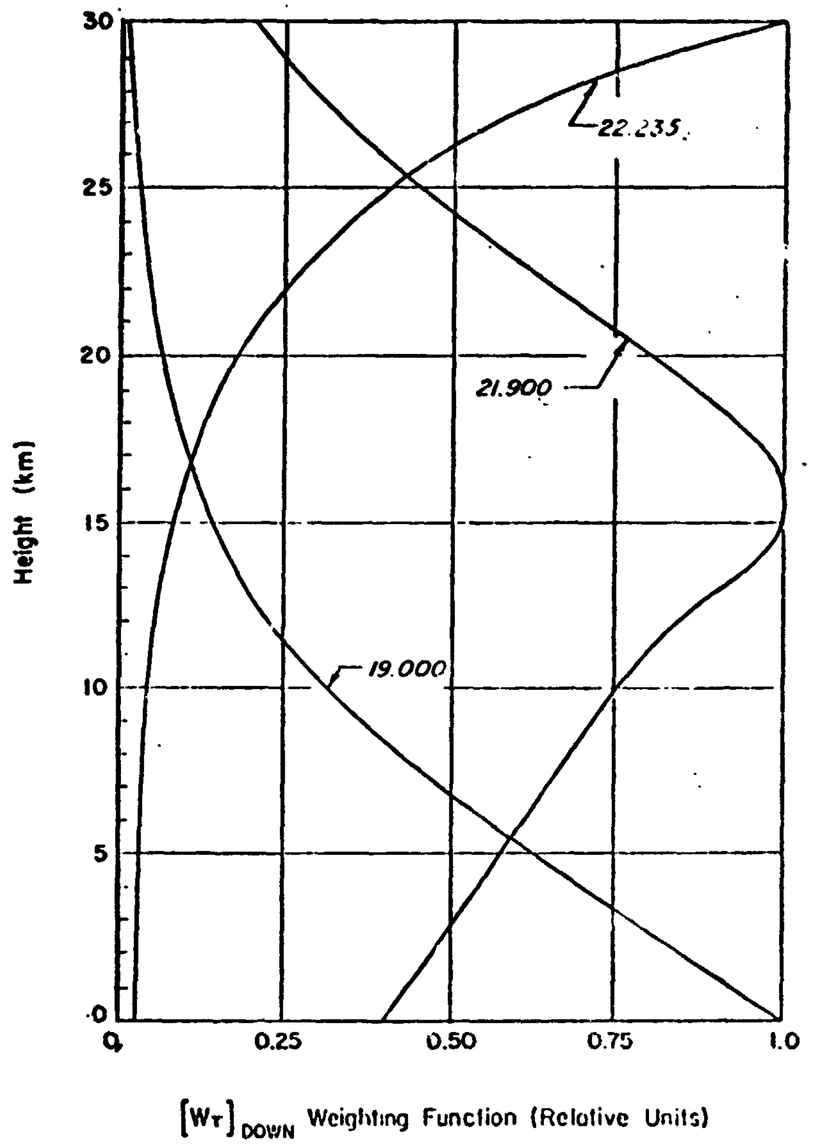



Figure 4. Water Vapor Weighting Functions

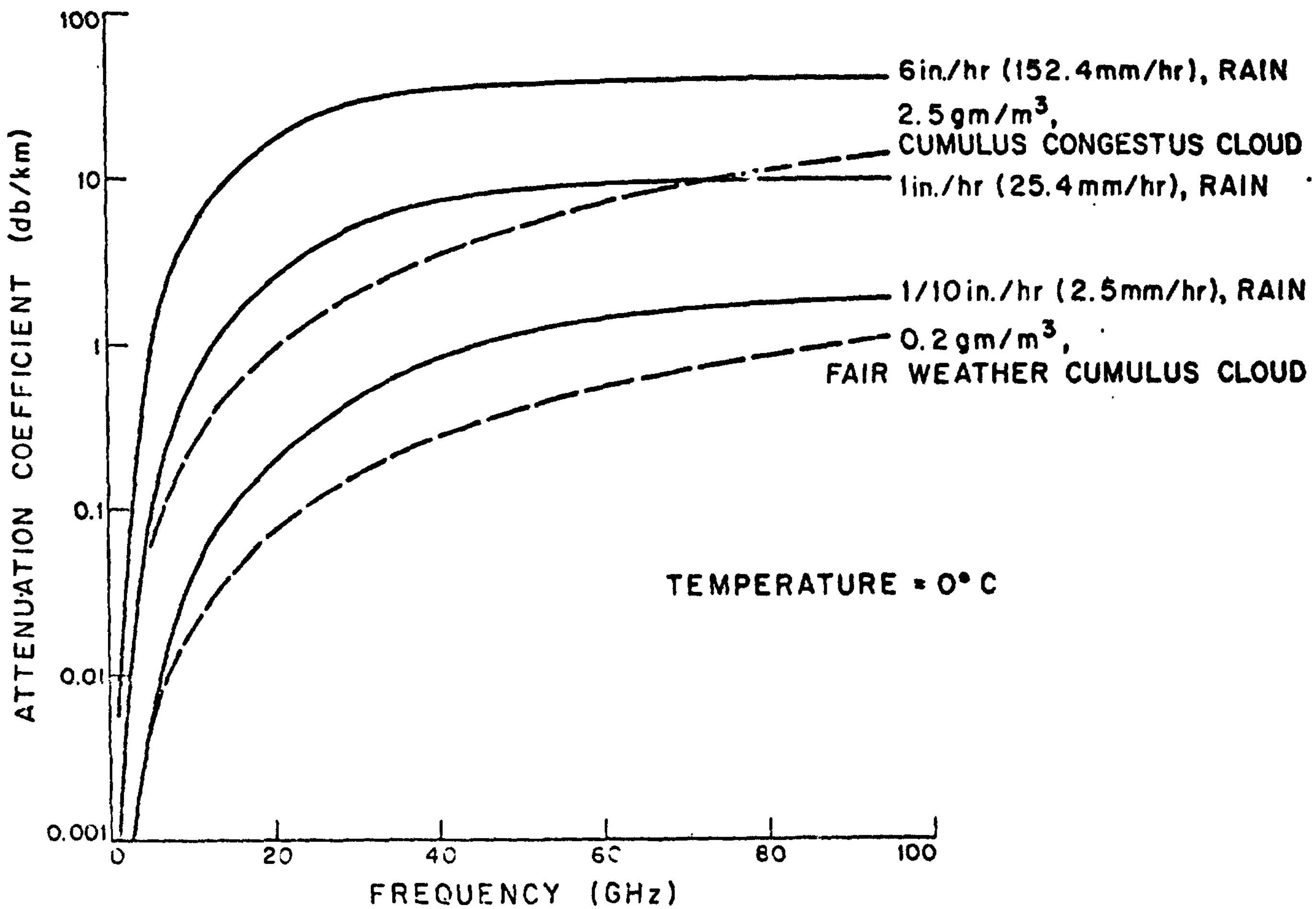



Figure 5. Attenuation Coefficient for Liquid-Water Scatterers

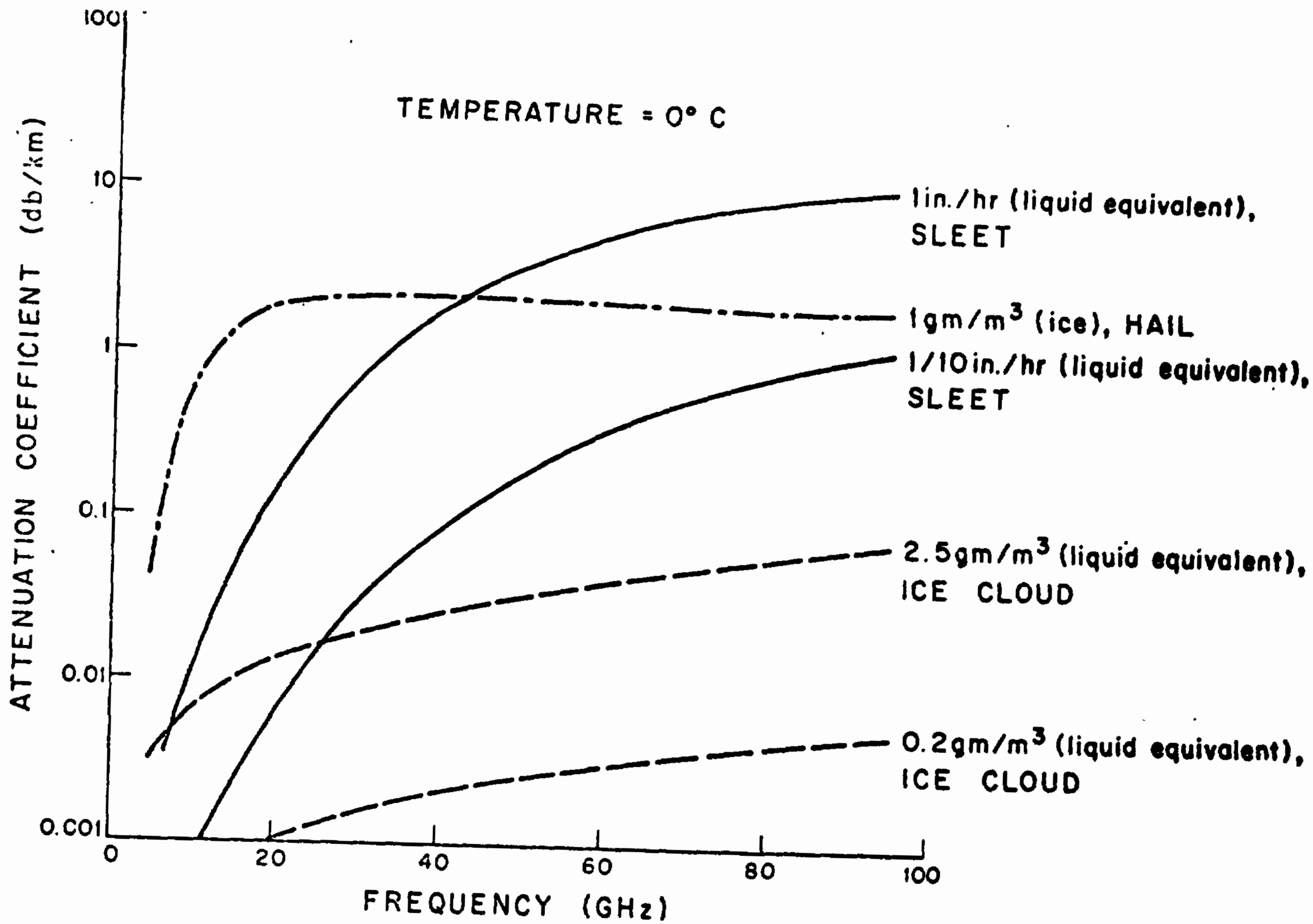



Figure 6. Attenuation Coefficient for Ice Scatters (Spherical)

ORIGINAL PAGE IS
OF POOR QUALITY

that is lost due to attenuation. The ratio of energy scattered to that lost by absorption is called the single scattering albedo[1]. Figure 7 depicts the single scattering albedo as a function of frequency for liquid and ice scatterers. If the single scattering albedo is zero, equations (9) and (2) hold but when the single scattering albedo is not zero the effect of scattering must be included in the radiative transfer equation. When the single scattering albedo is near one, attenuation is primarily due to scattering and not to absorption. Under these conditions, little emission is generated by the scatterers although the scatterers still attenuate the emission upwelling from lower regions of the atmosphere and from the surface.

## Surface Emission

Emission from the surface of the earth is transmitted through the atmosphere to the satellite. When the attenuation values are high, this emission cannot be sensed. When it is low, as required to sense the temperature of the lowest layer of the atmosphere, both the surface and atmospheric contributions are combined. Additional measurements within the window channels are required to separate the two types of contributions. Surface emission is proportional to the temperature and emissivity of the surface. The latter are related to the dielective properties of the surface and to the roughness of the surface. If the emissivity is less than unity, the surface both emits and scatters radiation. The scattered radiation originates from downward atmospheric emission from above the surface. In a window channel with very small attenuation values this latter contribution is negligible; otherwise it must be considered in the solution of equation (1).

Surface brightness temperatures do not show the rapid variation with frequency exhibited by emission from atmospheric absorption lines. The relatively slow frequency variations of the effects of surface parameters requires simul-

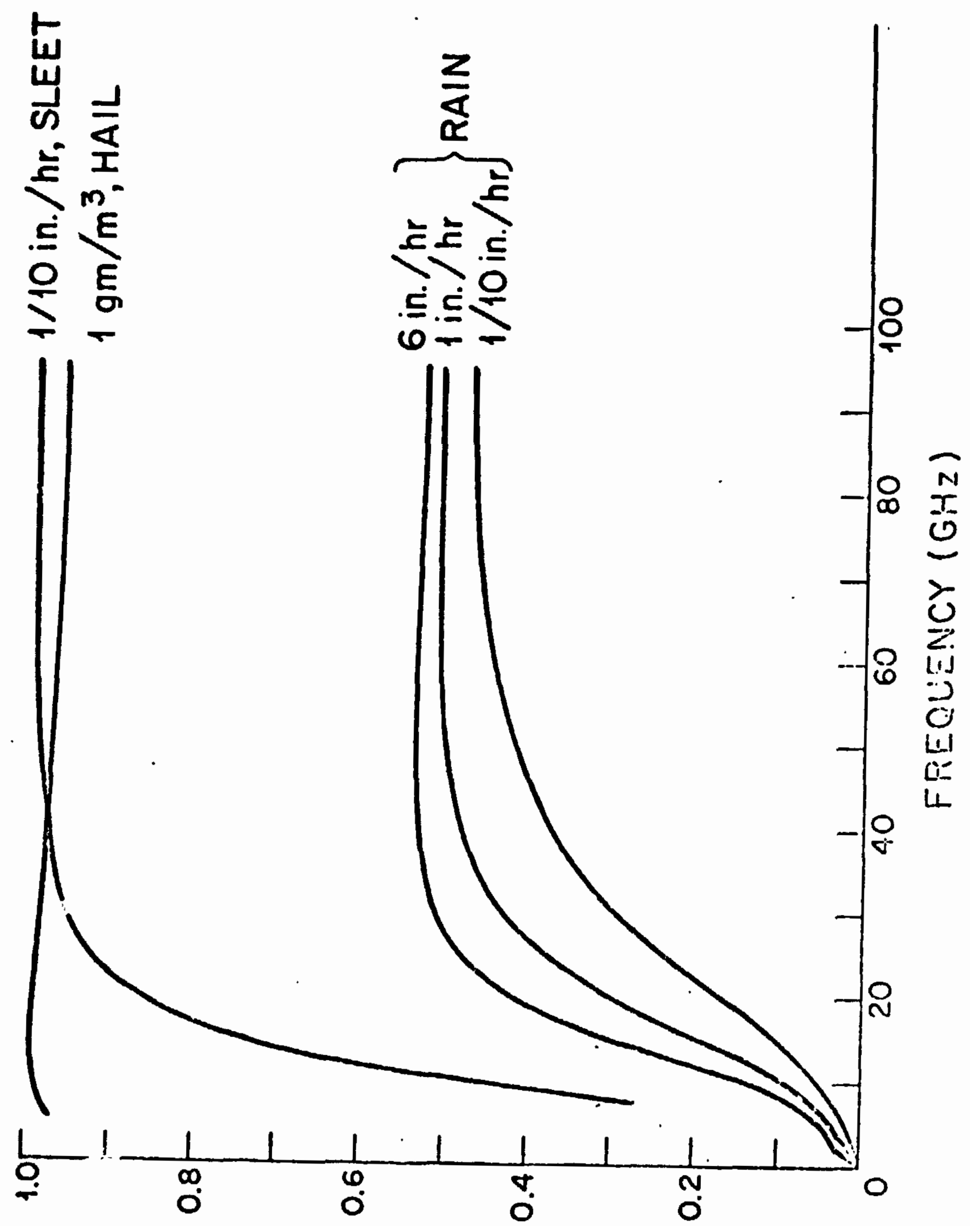



Figure 7. Scattering Albedo vs. Frequency

ORIGINAL PAGE IS
OF POOR QUALITY

taneous observations over a broad frequency range within the atmospheric windows to determine their values. Separation of the parameters can only be accomplished when the parameters have different frequency dependences[4,5]. Figs. 8, 9 and 10 depict the frequency dependence of the several parameters that affect the brightness temperature of the ocean surface, salinity, temperature, and wind. The wind affects the brightness temperature by roughing the surface and by producing foam which has dielectric properties different from the underlying water. These figures show that salinity is best sensed at frequencies below 3 GHz and, if extreme measurement accuracy is required, at frequencies below 1.5 GHz. Sea surface temperature is best sensed using frequencies in the 3 to 10 GHz range with 5 GHz being optimum. Wind affects observations at all frequencies but is best sensed at frequencies above 15 GHz.

Surface layers of ice or oil that float on the surface have dielectric properties different from water and can be sensed due to the resultant change in brightness temperature. Oil slicks can change the brightness temperature above 30 GHz by more than 50°K[6] and ice can change the brightness temperature by more than 50° at frequencies from 1 to 40 GHz[7]. Although ice and oil spills can provide a large change in brightness temperature, a number of observations in each of the atmospheric windows are required to separate the effects of ice and snow from rain and clouds.

The moisture content of the surface layers can be detected at microwave frequencies[8]. The brightness temperature of snow and of soil both change with moisture content and with frequency. In general, the lower the frequency, the thicker the layer that can be sensed. Since the moisture at the surface is related to the profile of moisture below the surface, observations at higher frequencies can also be useful. In sensing the melting of snow near the surface, observations at 37 GHz and higher provide the most information. For sensing soil, especially soil under a vegetation canopy,

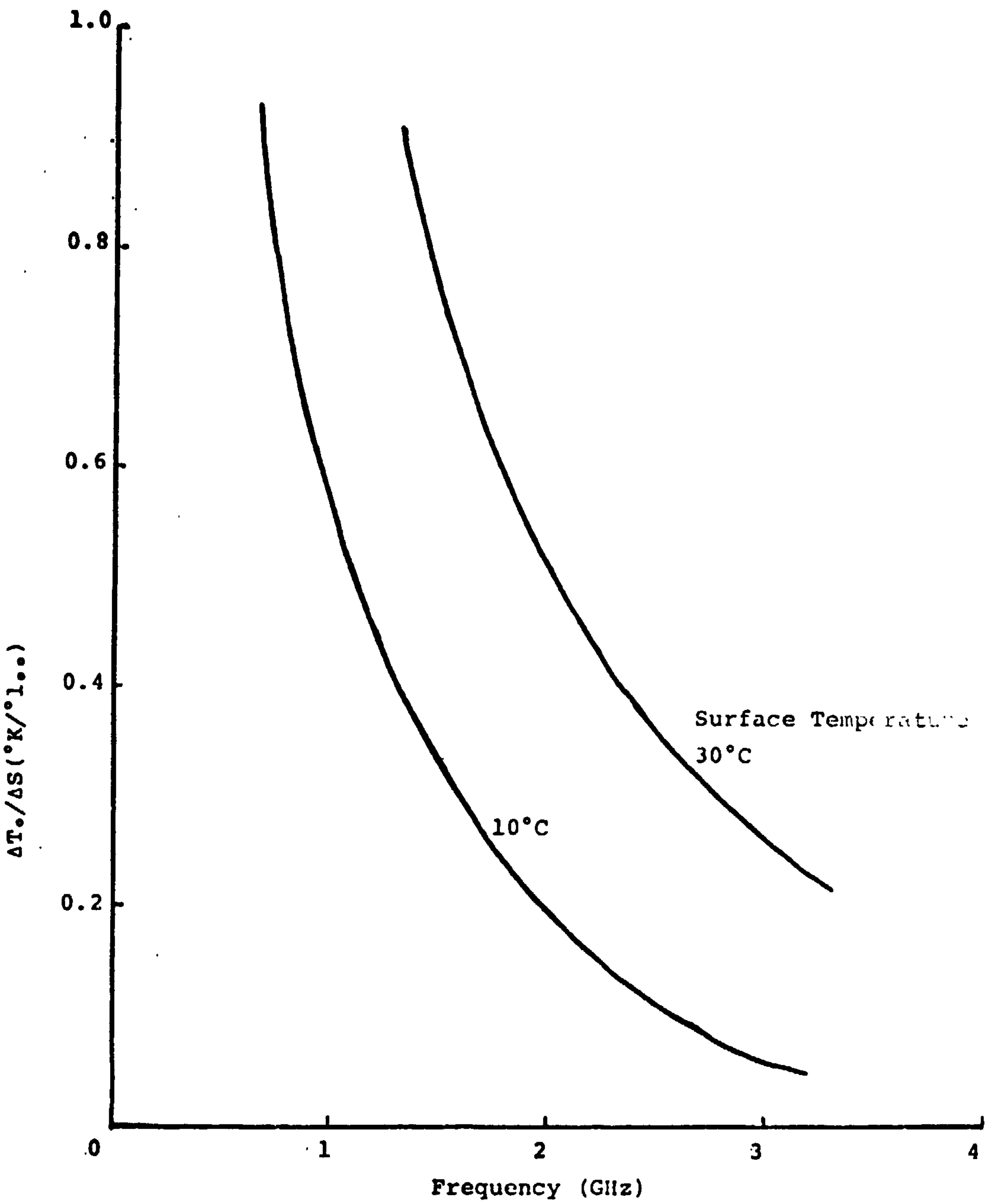



Figure 8. Change in Brightness Temperature with Salinity

ORIGINAL PAGE IS OF POOR QUALITY

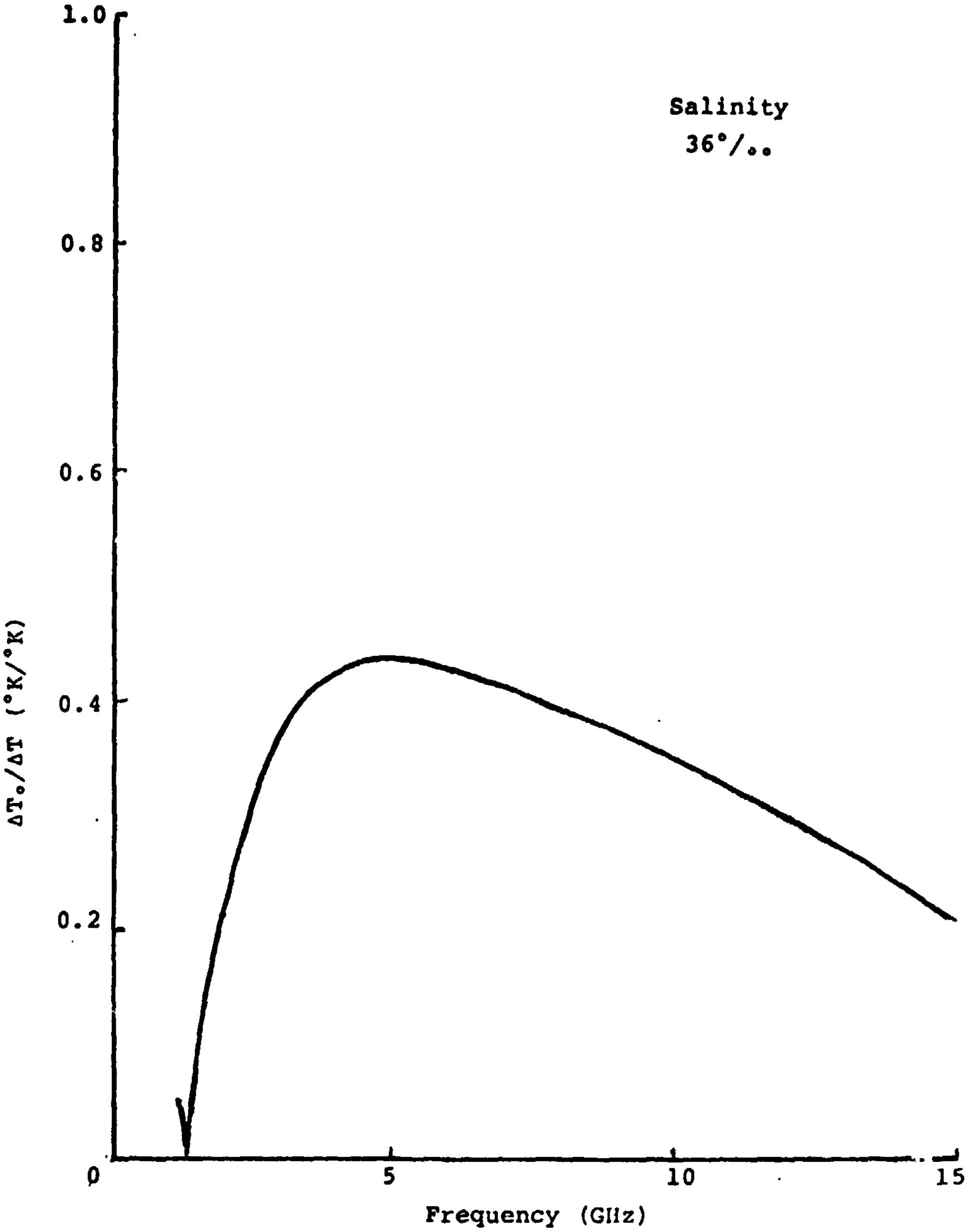



Figure 9. Change in Brightness Temperature with Surface Temperature

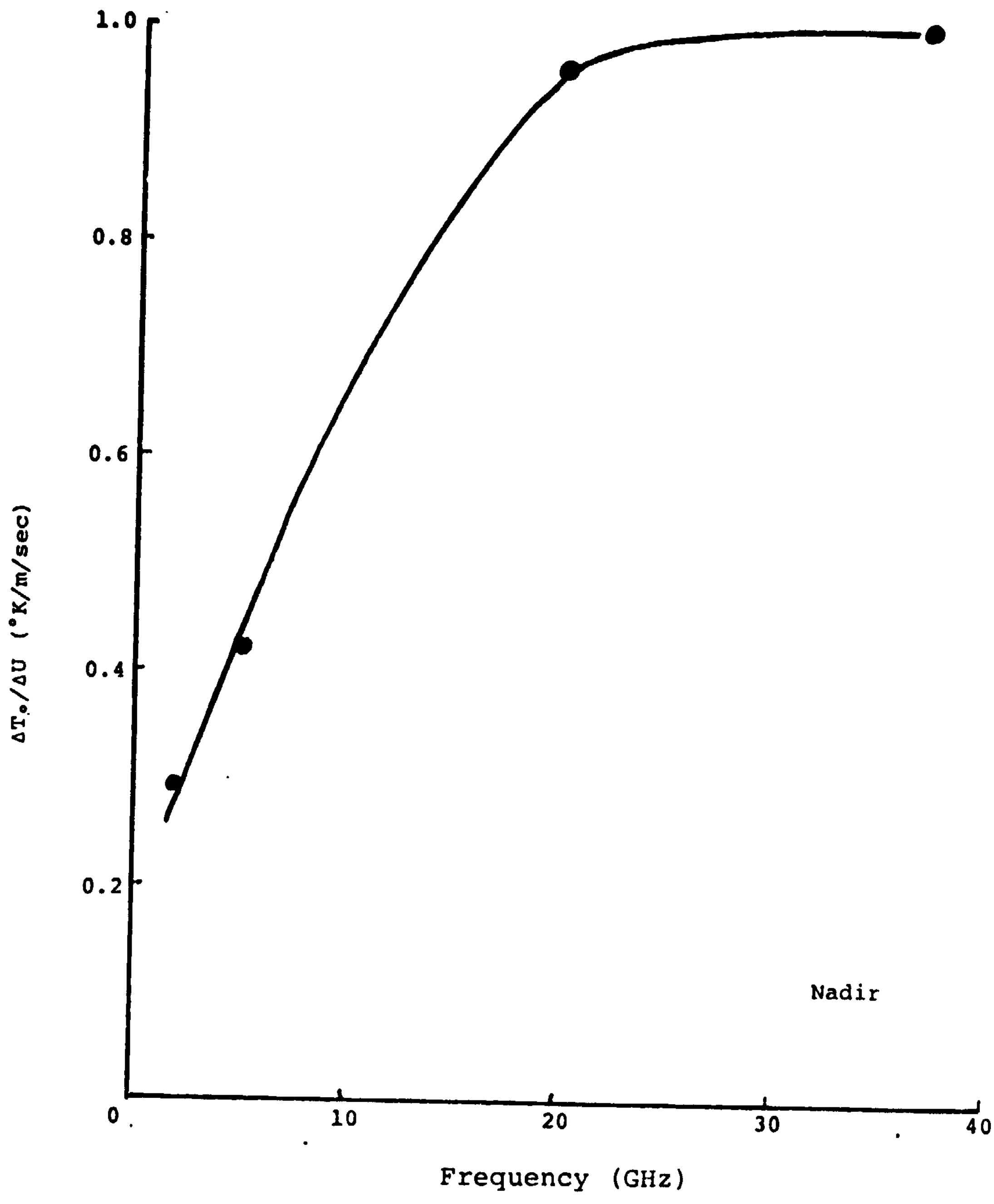



Figure 10. Change in Brightness Temperature with Wind Speed

ORIGINAL PAGE IS
OF POOR QUALITY

frequencies below 3 GHz are of most interest. In practice a number of frequencies are required first to classify the surface as to roughness, vegetation cover, sea ice age, etc., and second to measure parameters such as ice thickness or moisture content. Figures 11, 12, and 13 present sensitivity curves versus frequency for ice[10], soil moisture[11], and snow[12].

## Radiometer Sensitivity

Radiometric receivers sense the noise like thermal emission collected by the antenna and the thermal noise of the receiver. By integrating the received signal the random noise fluctuations can be reduced and accurate estimates can be made of the sum of the receiver noise and external thermal emission noise power. Expressing the noise power per unit bandwidth as an equivalent noise temperature, the effect of integration in reducing measurement uncertainty can be expressed as[9]

$$\Delta T = \frac{\alpha (T_A + T_N)}{\sqrt{B\tau}}$$

where $\Delta T$ = rms uncertainty in the estimation of the total system noise, $T_A + T_N$

$T_A$ = antenna temperature

$T_N$ = receiver noise temperature

$B$ = bandwidth

$\tau$ = integration time

$\alpha$ = receiver system constant.

There are two types of microwave radiometers--total power and Dicke[10]. Total power radiometers measure the noise power received by the antenna, as well as that generated by the receiver system. However, they are subject to calibration errors due to receiver system drift. Dicke radiometers, on the other hand, rapidly switch the input of

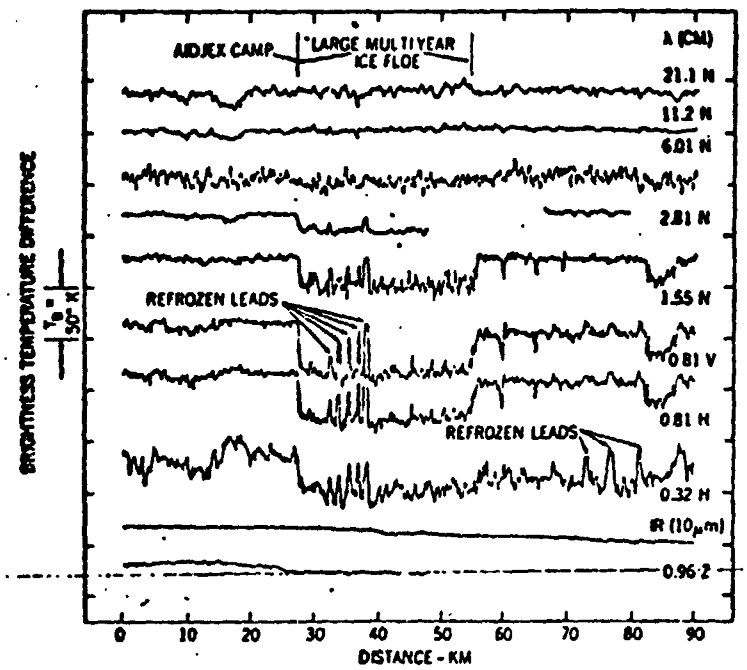



Figure 11. Brightness Temperatures of Ice at Various Frequencies

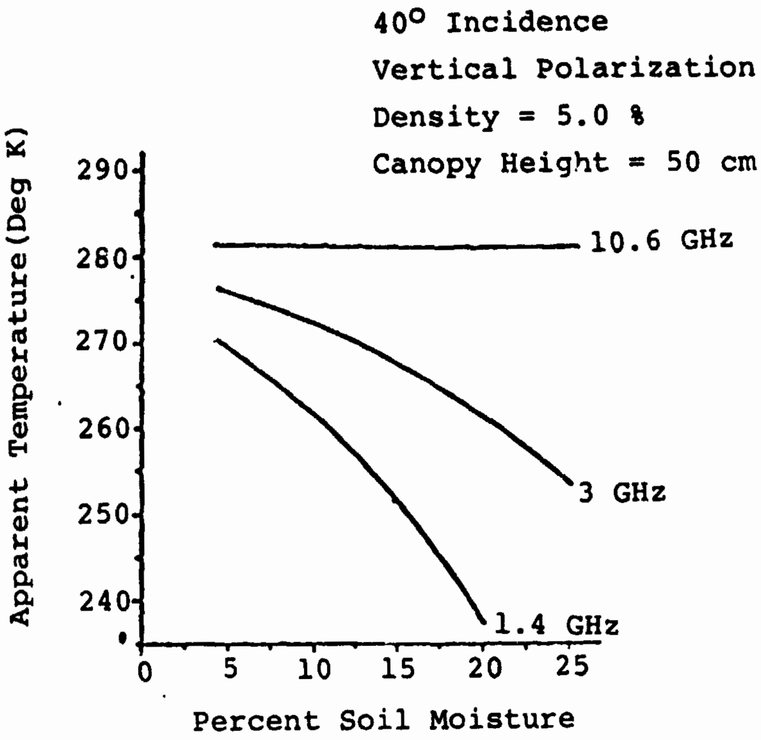



Figure 12. Apparent Temperature of a Uniformly Vegetated Smooth Surface for Various Frequencies

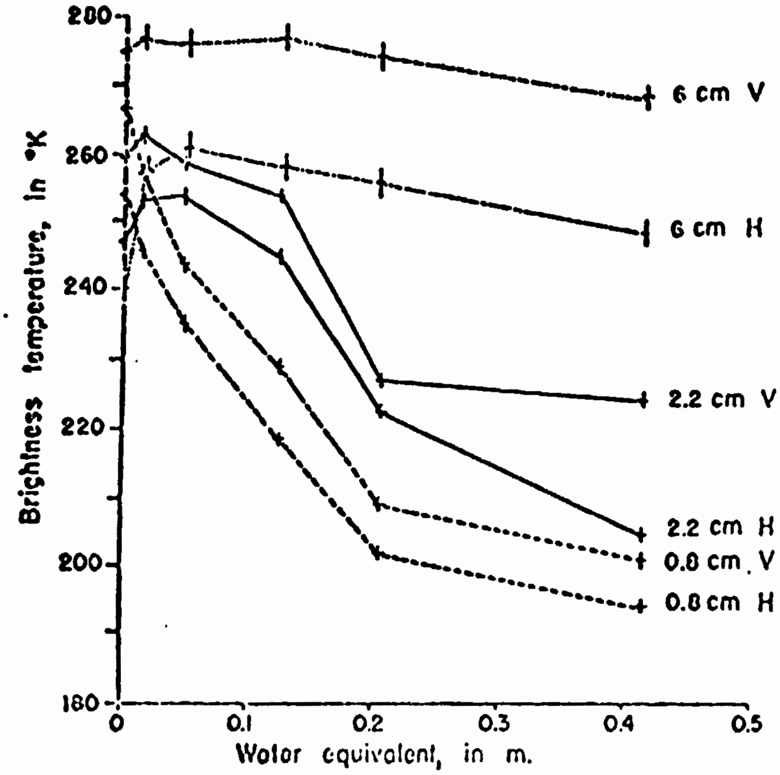



Figure 13. Measured Dry Snow Brightness Temperatures at Various Frequencies and Polarizations

ORIGINAL PAGE IS OF POOR QUALITY

the receiver system between the antenna and a load at a known temperature in order to secure proper calibration. The Dicke receiver output is detected synchronously with the input switching rate and the difference between the two signals is amplified and averaged to provide an output proportional to the difference between the antenna temperature and load temperature. The Dicke radiometer is sensitive to gain changes, but less so than a total power radiometer since amplification at the critical stages in the Dicke receiver system can be performed with ac coupled stages tuned to the switching rate rather than by dc coupled stages. In practice, Dicke radiometers are easier and less expensive to construct, operate and maintain than total power radiometers that provide the same protection against reciver system drift calibration errors.

For an ideal total power radiometer, $\alpha = 1$; for an ideal Dicke radiometer, $\alpha = \sqrt{2}$; and for a practical Dicke radiometer $\alpha = 2$. The bandwidth calculations made for Chapter I and Chapter II, Part B, assumed $\alpha = 2$ unless otherwise stated.

## REFERENCES


1. R.K. Crane; 1971 "Propagation Phenomena Affecting Satellite Communication Systems Operating in the Centimeter and Millimeter Wavelength Bands" Proc. IEEE 59 173-188.

2. D.H. Staelin; 1969 "Passive Remote Sensing at Microwave Frequencies" Proc. IEEE 57 427-439.

3. N.E. Gaut, E.C. Reifenstein III, D.T. Chang, and J.C. Blinn III; 1973 "Analysis of Microwave Sounding Systems" Final Report ERT Project P-553, Environmental Research & Technology, Inc., Lexington, Mass.

4. N.E. Gaut, E.C. Reifenstein III, and D.T. Chang; 1972 "Microwave Properties of the Atmosphere, Clouds and the Oceans" Final Report ERT Project P-280, NASA Contract NAS5-21624, Environmental Research & Technology, Inc., Lexington, Mass.

5. M.G. Fowler, J.H. Willand, D.T. Chang, and R.G. Isaacs; 1976 "Estimation of the Geophysical Properties of the Ocean Surface Using Aircraft Microwave Measurements" Final Report ERT Project 1143, NASA Contract NAS5-20619, Environmental Research & Technology, Inc., Concord, Mass.

6. J.P. Hollinger and R.A. Mennella; 1973 "Oil Spills: Measurements of Their Distributions and Volumes by Multifrequency Microwave Radiometry" Science 181 54-56, 6 July 1973.

7. J.C. Blinn III; 1975 "Microwave Measurements of Ice Thickness" Final Report ERT Project P-791, JPL Contract No. 953748, Environmental Research & Technology, Inc., Lexington, Mass.

8. T. Schmugge, P. Gloersen, T. Wilheit, and F. Geiger; 1974 "Remote Sensing of Soil Moisture With Microwave Radiometers" J. of Geophys. Res. 79 317-323.

9. J.D. Kraus, 1966; Radio Astronomy, McGraw-Hill, New York.

10. R.H. Dicke, R. Beringer, R.L. Kyhl, and A.B. Vane; 1946; "Atmospheric Absorption Measurements with a Microwave Radiometer" Phys. Rev. 70 340-348.


ORIGINAL PAGE IS
OF POOR QUALITY

# CHAPTER II

## PART B

## USER REQUIREMENTS AND DETAILED SHARING ANALYSES

# SECTION 1

## FREQUENCY BAND 10.6 - 10.7 GHz

## USER REQUIREMENTS

The primary measurements in this band are sea state, rain, snow and ice morphology. The principal measurement is for sea state. Sea state measurements are used to indicate wind speeds, which are important to meteorologists and the shipping industry. Sea state observations may be made at frequencies above 1 GHz, but due to the competing effects of sea surface temperature at lower frequencies, and clouds and rain at higher frequencies, 10.6-10.7 GHz is optimum for wind speed measurement.

The maximum resolution must be 2-5 km in order to support estuarine wind speed observations. Measurements with this spatial resolution are required to separate land and water features. However, rain measurements over land demand an even smaller spatial resolution, 1 km, in order to differentiate different surface backgrounds and to map convective rain cells. Convective rain cells have median horizontal dimensions of slightly less than 3 km. For a satellite in a 500 km circular orbit, the beamwidth for a 1 km resolution at the surface is 0.1°, and this requires an antenna of 15-20 meters, depending upon pointing angle. Since a point on the surface is within the antenna beam for less than 0.1 second, the maximum integration time is 0.1 second.

The measurement range for wind speed is 0-30 m/sec. and requires measurements with a 1.5 m/sec. accuracy (5 percent).

For nadir observations, the required radiometer sensitivity is 1.0 K (see Part A, for sensitivity curves). For off-nadir observations, the measurement accuracy increases or decreases slightly depending upon polarization. Measurements at all polarizations for observations over a 1000 km wide swath may be obtained with a 1 K radiometer sensitivity.

Assuming a Dicke switched radiometer with a 1000 K noise temperature, the minimum bandwidth for a 1 K sensitivity and a 0.1 second integration time is 60 MHz. Significantly larger bandwidths are required to economically support mapping applications with a scanning beam system. For estuarine surface observations, a 2 km spatial resolution is adequate, and 3 beam positions may be scanned using a 100 MHz bandwidth and 0.066 second integration time. Multiple, 3-beam position scanning antennas would be required to image a swath.

Estuarine surface observations made for environmental regulation enforcement are required on a once per day basis. Observations in support of rain measurements may be required as often as once per hour.

## SHARING ANALYSIS

The lower 80 MHz of the 10.6-10.7 GHz frequency band is currently allocated on a primary basis to the Fixed and Mobile Services on a world-wide basis. The upper 20 MHz (10.68-10.7 GHz) is currently allocated to the Radio Astronomy Service on a world-wide basis, except that Radio Regulation Footnote 405B permits fixed and mobile operations in Algeria, Bulgaria, Cuba, Hungary, Japan, Lebanon, Pakistan, Poland, United Arab Republic, Yugoslavia, Romania, Czechoslovakia and the USSR. Since passive sensors can inherently share with the Radio Astronomy Service, the following analysis considers only sharing with the Fixed and Mobile Services from 10.6 to 10.68 GHz.

### 1.1 Technical Characteristics

Current U. S. and international frequency assignment data files indicate that there is presently little usage of the 10.6-10.68 GHz band by the Fixed and Mobile Services.

In the United States, only 12 assignments are currently listed in FCC data files. The systems, both fixed and mobile, operate at output power levels of less than 1 watt, and are apparently used for public safety or industrial-type services.

Similarly, IFRB data files indicate few assignments in the 10.6-10.68 GHz frequency band. There are only 5 listings in Europe and Japan combined, and these specify output powers of 1 watt or less.

Assuming the technical characteristics listed in FCC and IFRB data files to be representative of systems operating in this band, the following terrestrial system characteristics are assumed for this analysis:

| | | |
|---|---|---|
| Transmitter Power | = | 0 dB(W) |
| Antenna Gain | = | 38 dB(i)* |



## 1.2 Sharing Considerations

### 1.2.1 Simultaneous Operations

As can be seen from the following, interference does not occur to the radiometer even when in the main beam of a terrestrial system.

| | | |
|---|---|---|
| Transmitter Power | = | 0 dB(W) |
| Antenna Gain | = | 38 dB(i) |
| Spreading Loss | = | -139 dB($m^{-2}$) |
| Radiometer Antenna Back-lobe Effective Area | = | - 56 dB($m^2$) |
| | | -157 dB(W) |

or 1 dB above the interference threshold of -158 dB(W).**

*Due to a lack of data, this value is assumed.

**Interference would occur from a direct overhead pass of the interferor. However, the duration of interference is considered of negligible impact to overall data measurements in an operational system.

Figure 1-1 presents the results of the multi-system interference environment using the Random Interference Analysis Program described in Appendix II. The figure relates the probability of data loss for the principal measurement, versus the number of terrestrial transmitters simultaneously operating and visible to the radiometer. As can be seen, a very large number of terrestrial systems can be simultaneously operating within view of the radiometer without causing significant levels of data loss.

Considering the present small population of terrestrial systems operating in the band, simultaneous operational sharing is considered feasible between the two Services. Future growth of terrestrial systems in this band, however, should be limited in order for sharing to continue to be feasible.

## 1.3 Conclusions on Sharing with the Fixed and Mobile Services

Sharing on a simultaneous operational basis between space-borne passive microwave sensors and the Fixed and Mobile Services in the 10.6-10.7 GHz region is feasible. Consequently, the space passive services can share on a primary, co-equal basis with the Fixed and Mobile Services. The following footnote should be included:

> "Fixed and mobile systems operating in the 10.6-10.7 GHz portion of the 10.6-10.95 GHz fixed and mobile allocation, are limited to 1 to 2 watt transmitter powers. Fixed and mobile systems with higher powers must use the 10.7-10.95 GHz portion of the allocation."

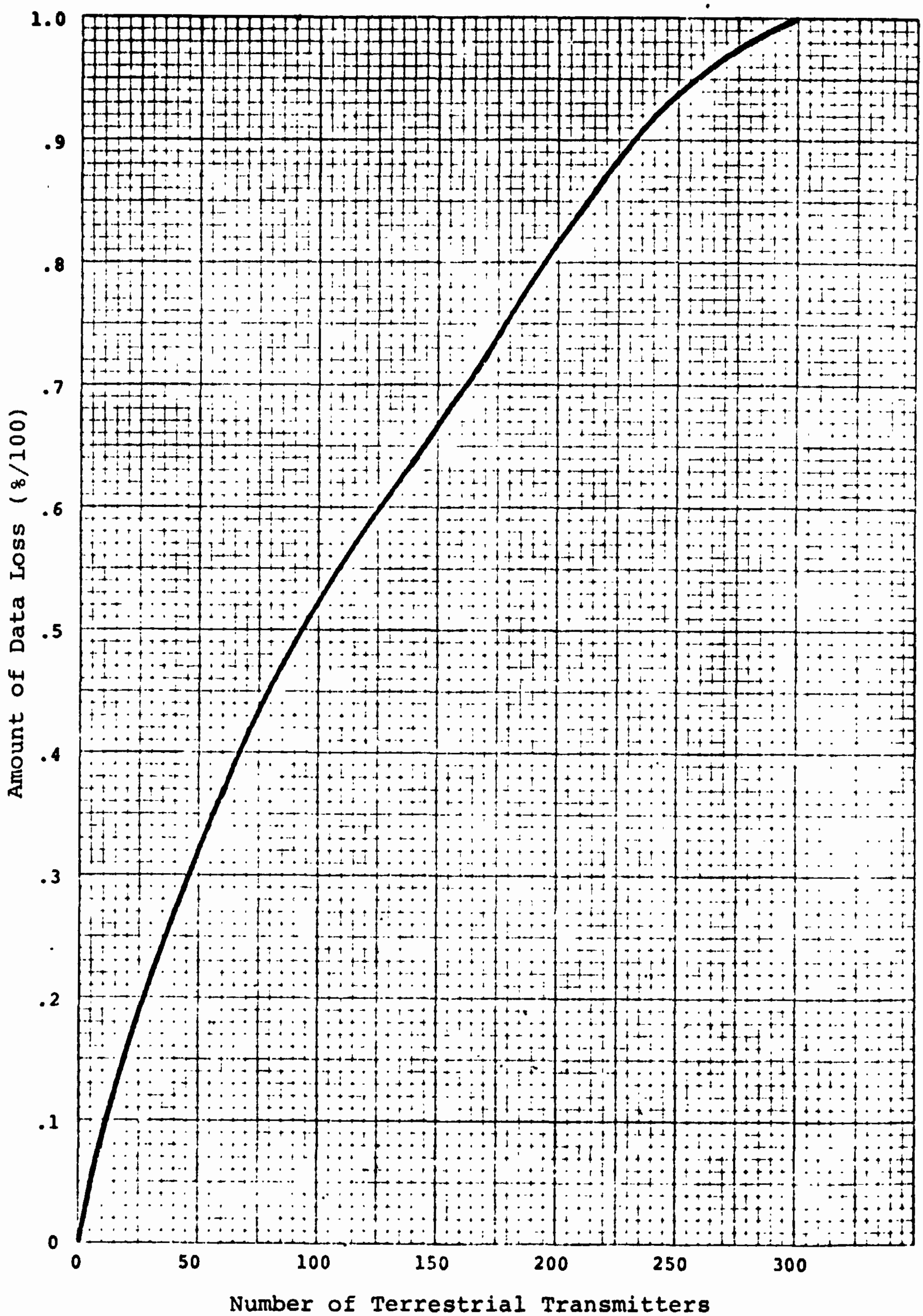



Figure 1-1 Data Loss vs. Number of Terrestrial Transmitters

# SECTION 2

# FREQUENCY BAND 15.3 - 15.5 GHz

## USER REQUIREMENTS

The primary measurements in this band are water vapor profiling and rain. The principal measurement is water vapor. The water vapor molecules have a rotation absorption line at 22.235 GHz which is pressure broadened in the lower atmosphere to produce a slight, but measurable absorption at this frequency. Observations at this frequency are required to establish the relative amount of water vapor in the boundary layer of the atmosphere.

Water vapor measurements are required over land and water. Observations over land are affected by variations in surface parameters, and must be made using a spatial resolution of 2 km or less in order to reduce the effect of surface variations within a beamwidth. For a satellite in a 500 km circular orbit, a 2 km resolution requires a beamwidth of 0.2° (5-7 meter antenna, depending on pointing angle). The antenna beam passes over a point on the surface in less than 0.2 seconds, requiring an integration time of less than 0.2 seconds.

The range of total precipitable water is 0-7 $g/cm^2$. The accuracy required for estimating the contribution of the lower boundary layer is 0.3 $g/cm^2$. To accomplish this at 15.3-15.5 GHz, a radiometer sensitivity of 0.2 K is required. (See Part A for sensitivity curves.)

Assuming a total power radiometer with a 1000 K noise temperature, a 0.2 K sensitivity and a 0.2 second integration time, a bandwidth of 180 MHz is required. A conventional Dicke switched radiometer would require a 720 MHz bandwidth.

Water vapor profiles are required twice per day for support of weather forecasting services. The update rate is controlled by the input requirements of the numerical forecasting programs operated by the National Weather Service.

# SHARING ANALYSIS

The lower 50 MHz of the 15.3-15.5 GHz frequency region is currently allocated to the Fixed and Mobile Services on a world-wide basis. The upper 100 MHz (15.4-15.5 GHz) is currently allocated to the Aeronautical Radionavigation Service on a world-wide basis, except that Radio Regulation Footnote 407 permits fixed and mobile operations in Albania, Bulgaria, Hungary, Poland, Romania, Czechoslovakia and the USSR.

The band 15.35-15.4 GHz is allocated to Radio Astronomy on a world-wide basis, except that Radio Regulation Footnote 409C permits Fixed and Mobile operations in Algeria, Bulgaria, Cuba, Hungary, Kuwait, Lebanon, Morocco, Pakistan, Poland, the United Arab Republic, Yugoslavia, Romania, Czechoslovakia and the USSR.

Since passive sensors can inherently share with the Radio Astronomy Service, the following analysis considers sharing with the Fixed and Mobile Services in the 15.3-15.35 GHz band, and the Aeronautical Radionavigation Service in the 15.4-15.5 GHz band.

### 2.1 Fixed and Mobile Services

Current U. S. and international frequency assignment data files indicate that there are presently no assignments in the 15.3-15.35 GHz band for the Fixed and Mobile Services. Since the Radio Regulations presently allocate Fixed and Mobile Services in this band, it is assumed that there will be operating systems at some time in the future. It is anticipated that the future use of Fixed and Mobile Services in the 15.3-15.35 GHz band would be concentrated in highly developed, populated areas, rather than the more sparsely populated and oceanic areas.

#### 2.1.1 Technical Characteristics

Fixed or Mobile Service development in the 15.3-15.35 GHz may utilize either analog or digital transmission techniques. However, since analog systems typically employ higher e.i.r.p.'s than digital, this analysis assumes analog fixed and mobile systems. Analog systems can be expected to be similar in objectives, operating parameters, and techniques to the existing Fixed and Mobile Services in lower regions of the microwave spectrum. Thus, the service would consist primarily of either fixed or transportable relay link facilities employing relatively high gain antennas. The technical characteristics for 15 GHz Fixed and Mobile Services can be estimated by examining the characteristics of operating systems below 10 GHz. These systems utilize links of about 20 km in length, and have the following operational parameters:

| | | |
|---|---|---|
| Transmitter Power | = | 13 dB(W) |
| Antenna Gain | = | 42 dB(i) |
| Transmit e.i.r.p. | = | 55 dB(W) |

Assuming that 20 km links are utilized at 15.3 GHz, the transmit e.i.r.p. requirement for such links can be computed by adding a factor to compensate for the increased operational frequency. Assuming a constant gain antenna at the receiver, a 15 GHz system e.i.r.p. requirement can be computed as follows:

| | | |
|---|---|---|
| Baseline e.i.r.p. | = | 55 dB(W) |
| Frequency factor | = | 3 dB |
| 15.3 GHz e.i.r.p. | = | 58 dB(W) |

Based on operational considerations (e.g., antenna, pointing accuracy, size, weight, transmitter technology, etc.), it is expected that a 58 dB(W) system e.i.r.p. would be generated differently for the Fixed and Mobile Services. Mobile systems, at a given frequency, tend to have smaller antennae, but larger transmitter powers than fixed systems. The estimated design parameters are given below:

| | FIXED | MOBILE |
|---|---|---|
| Transmitter Power | 13 dB(W) | 19 dB(W) |
| Antenna Gain | 45 dB(i) | 39 dB(i) |
| System e.i.r.p. | 58 dB(W) | 58 dB(W) |

### 2.1.2 Sharing Considerations

#### 2.1.2.1 Simultaneous Operations

The interference level in the main beam of a single interference source would occur on the horizon as seen from a fixed or mobile system. The level of the interference would be:

| | | |
|---|---|---|
| Transmitter Power | = | 19 dB(W)* |
| Antenna Gain | = | 39 dB(i) |
| Spreading Loss | = | -139 dB($m^{-2}$) |
| Atmospheric Absorption | = | - 5.6 dB |
| Radiometer Antenna Effective Area (Sidelobe) | = | - 59 dB($m^{-2}$) |
| | | -145.6 dB(W) |

or 14 dB above interference threshold of -160 dB(W).

The area of data loss due to a single mobile emitter of this type is shown in Figure 2-1, constituting about 1% of the visibility sphere.

The Random Interference Analysis Program** was utilized to simulate the multi-interferor environment based on the expected system parameters. Figure 2-2 presents the results

---

* Typical of a mobile station.

** See Appendix II.

of this analysis. The figure relates the probability of data loss versus the number of terre rial transmitters simultaneously operating and visible to the radiometer.

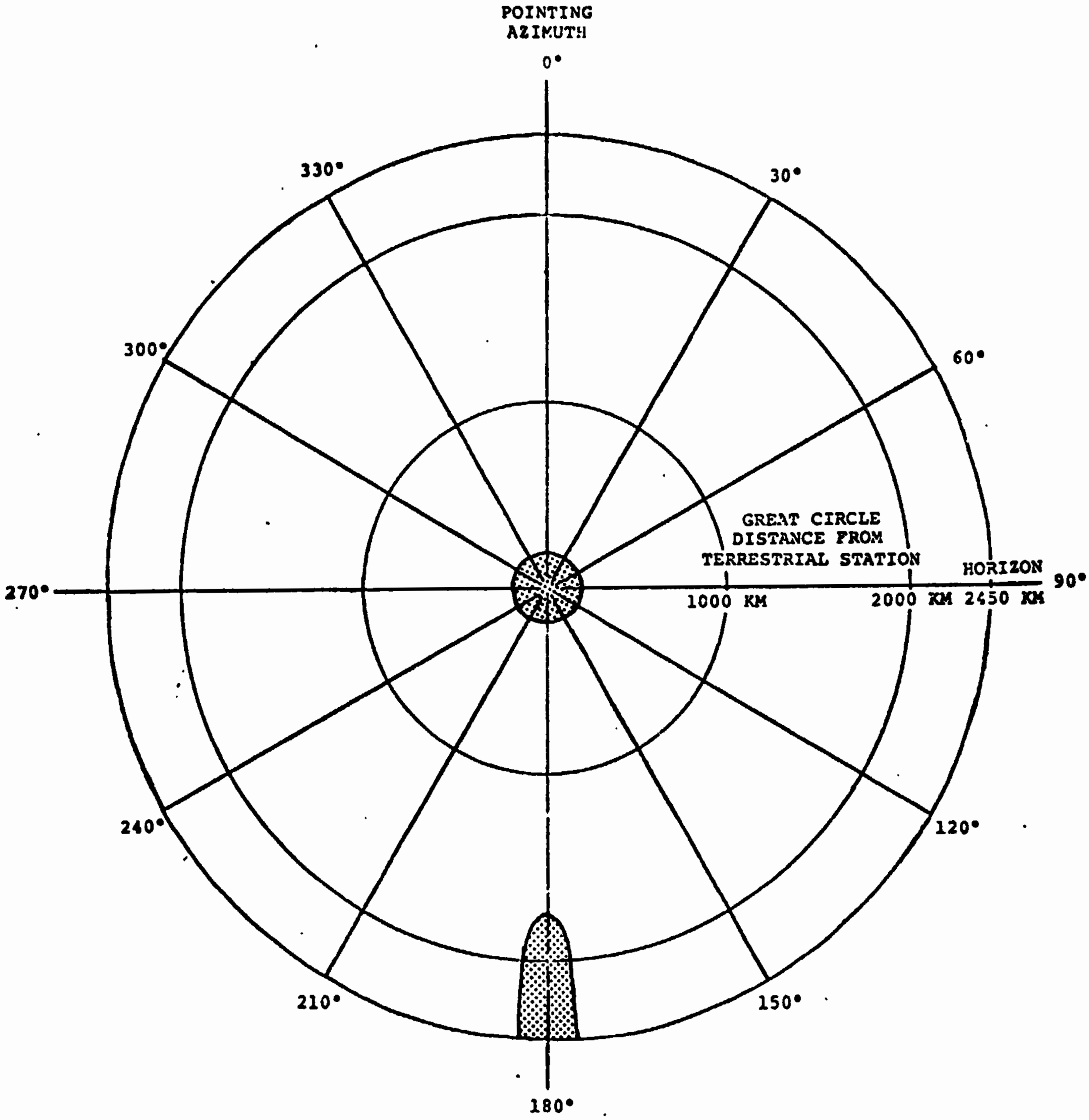
Although little is known as to the projected extent of usage by the Fixed and Mobile Services of this band, large amounts of data would be lost if approximately 50 transmitters are simultaneously in view of the radiometer. It is assumed that at least this number of transmitters would be simultaneously in view of the radiometer for line-of-sight relay systems; consequently, sharing on a simultaneous operations basis is considered infeasible.

2.1.2.2 Time Sharing

It is impossible to determine the duty cycles of operations for these as yet undetermined fixed and mobile systems. It cannot be assumed, however, that these systems will be inoperative during late night-early morning hours. Since time sharing could be accomplished only if nighttime restrictions on operating times could be imposed, it must be concluded that time sharing is not feasible.

2.1.3 Conclusions

Simultaneous operations between spaceborne passive microwave sensors and the Fixed and Mobile Services in the 15.3-15.35 GHz region are not feasible. Time sharing also is not considered feasible.




Note: Shaded areas indicate region where interference and therefore, loss of coverage occurs. Terrestrial station is located in center.

Figure 2-1 Loss of Coverage Area Due to Single Mobile Interferor

ORIGINAL PAGE IS
OF POOR QUALITY

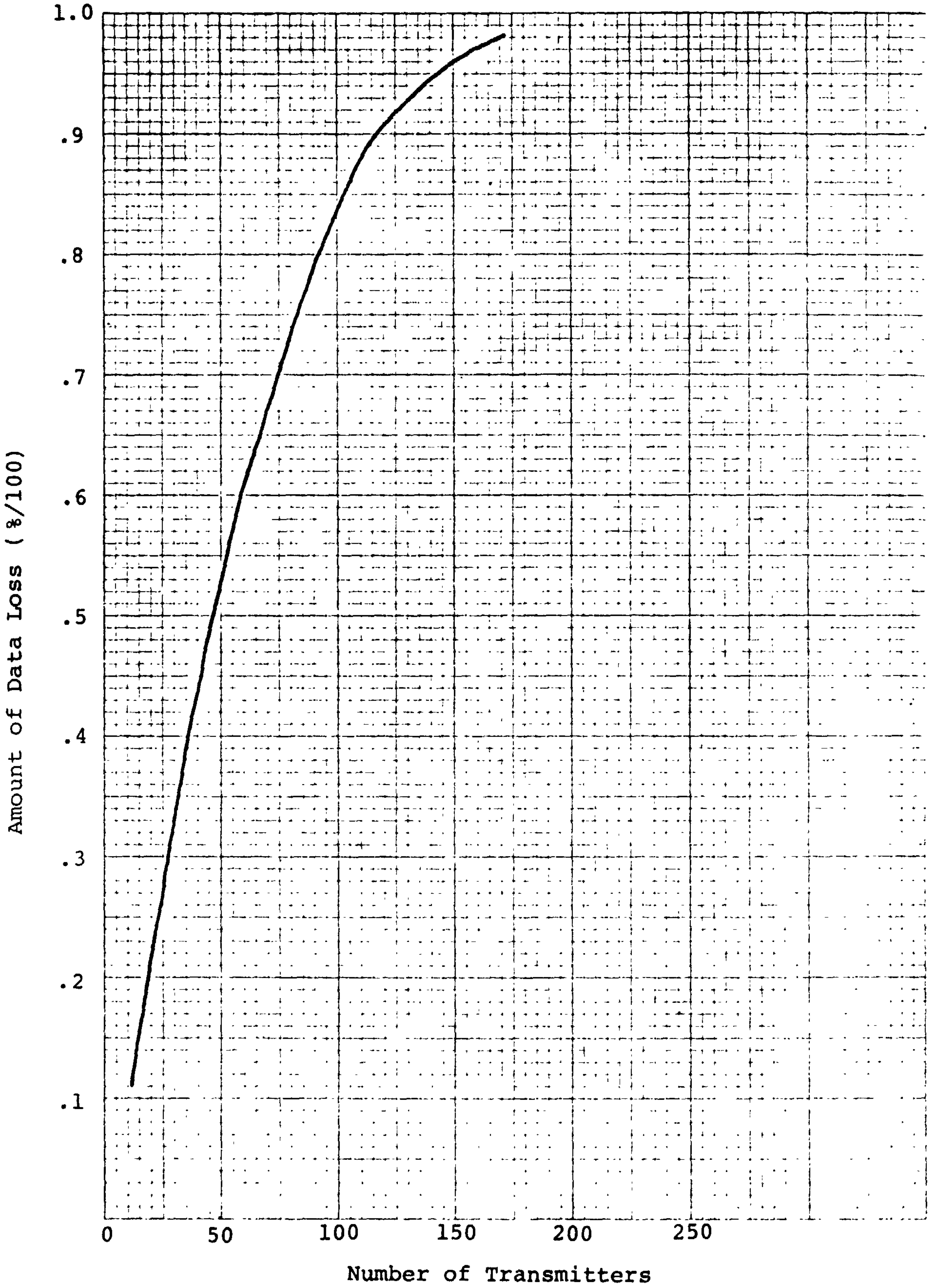



Figure 2-2 Data Loss vs. Number of Terrestrial Transmitters, Fixed and Mobile Services

## 2.2 Aeronautical Radionavigation Service

The primary planned use of the 15.4-15.5 GHz* band, is for a world-wide Microwave Landing System (MLS). MLS is designed to provide landing information for an aircraft on final approach to a runway. The system provides both lateral and vertical guidance, and is expected to improve flight safety. MLS is expected to be the standard approach system of the future, and will probably be installed at airports not now equipped with precision approach and landing systems. In the continental United States (CONUS), it is estimated that approximately 1600 MLS systems will be operational in 10 years, increasing to upwards of 3000 at the end of 20 years.

The planned FAA MLS systems will utilize low power transmitters, and for the purpose of this analysis, are referred to as "low power MLS".

There are a few listings with high power transmitters in the U. S. government data files for radionavigational aids. Personal contacts with military personnel have indicated that the number of these systems is anticipated to increase in the near future. For the purpose of this analysis these systems are referred to as "high power MLS".

### 2.2.1 Technical Characteristics

The following technical characteristics are considered typical of low and high power MLS respectively:

*The DOD and FAA, who plan to use the MLS, are presently determining the relative merits of using the 5.000-5.250 GHz and/or the 15.4-15.5 GHz band for the proposed Microwave Landing System. For this analysis the assumption has been made that the MLS system will be implemented at 15.4 GHz.

Low Power MLS

Transmitter Power = 7 dB(W)

Antenna Gain = 20 dB(i)

High Power MLS

Transmitter Power = 33 dB(W)

Antenna Gain = 43 dB(i)

### 2.2.2 Sharing Considerations

#### 2.2.2.1 Simultaneous Operations

For the low power MLS, the Random Interference Analysis Program* was utilized to simulate the interference environment. Figure 2-3 presents the results of the analysis. The figure relates the probability of data loss versus the number of terrestrial transmitters simultaneously operating and visible to the radiometer. Although a large number of low power MLS can be simultaneously operating within view of the radiometer without exceeding the interference threshold of -160 dB(W), it is expected that even larger numbers, based on FAA plans, will be in view of a spacecraft at 500 km orbital altitude.

The Gain Range Quotient Program* was utilized to determine the loss of coverage area due to operations of a single high power MLS. Figure 2-4 shows this area of coverage loss. The shaded area corresponds to approximately 14% of the total visibility.

---

* See Appendix II.

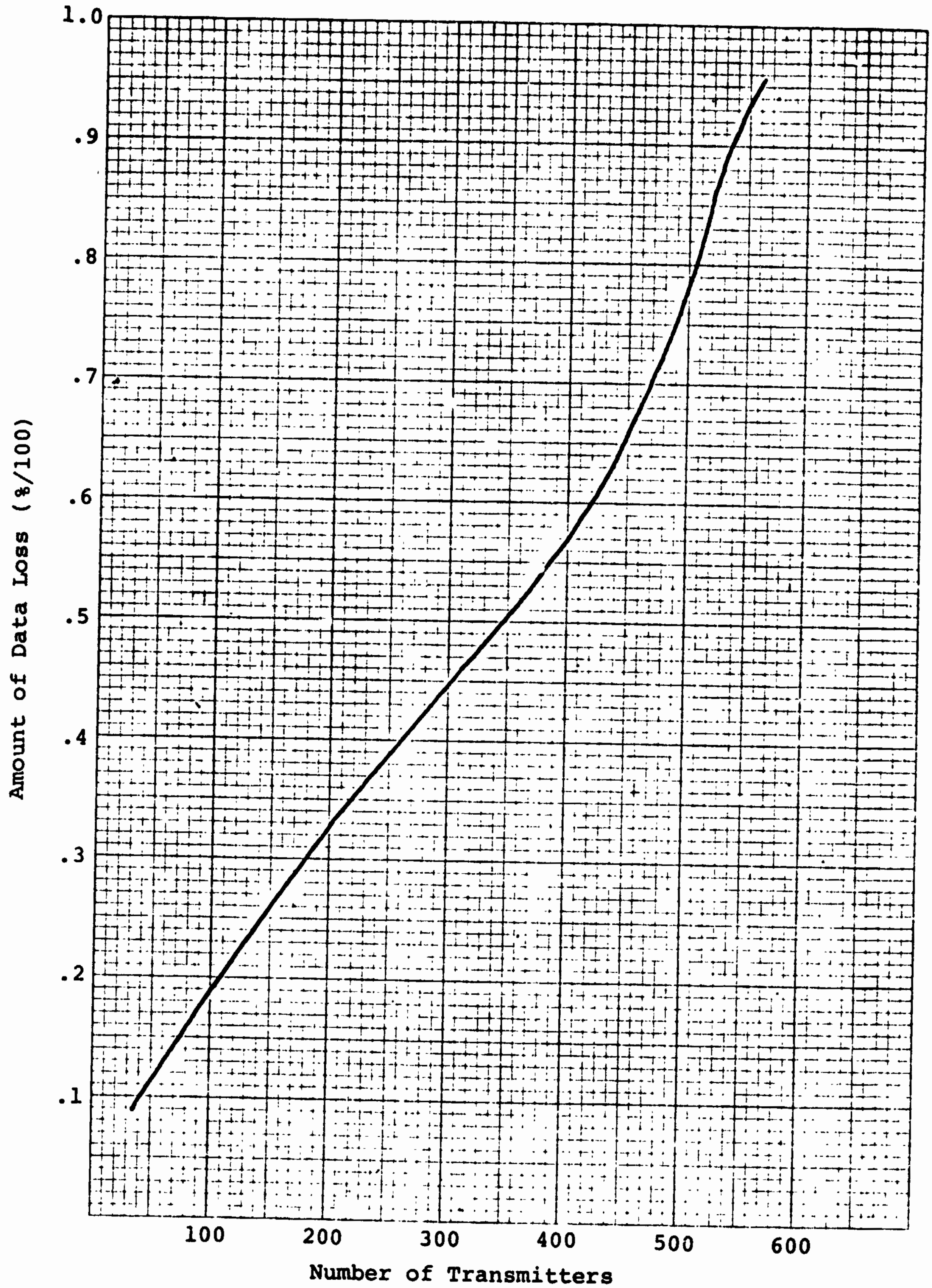
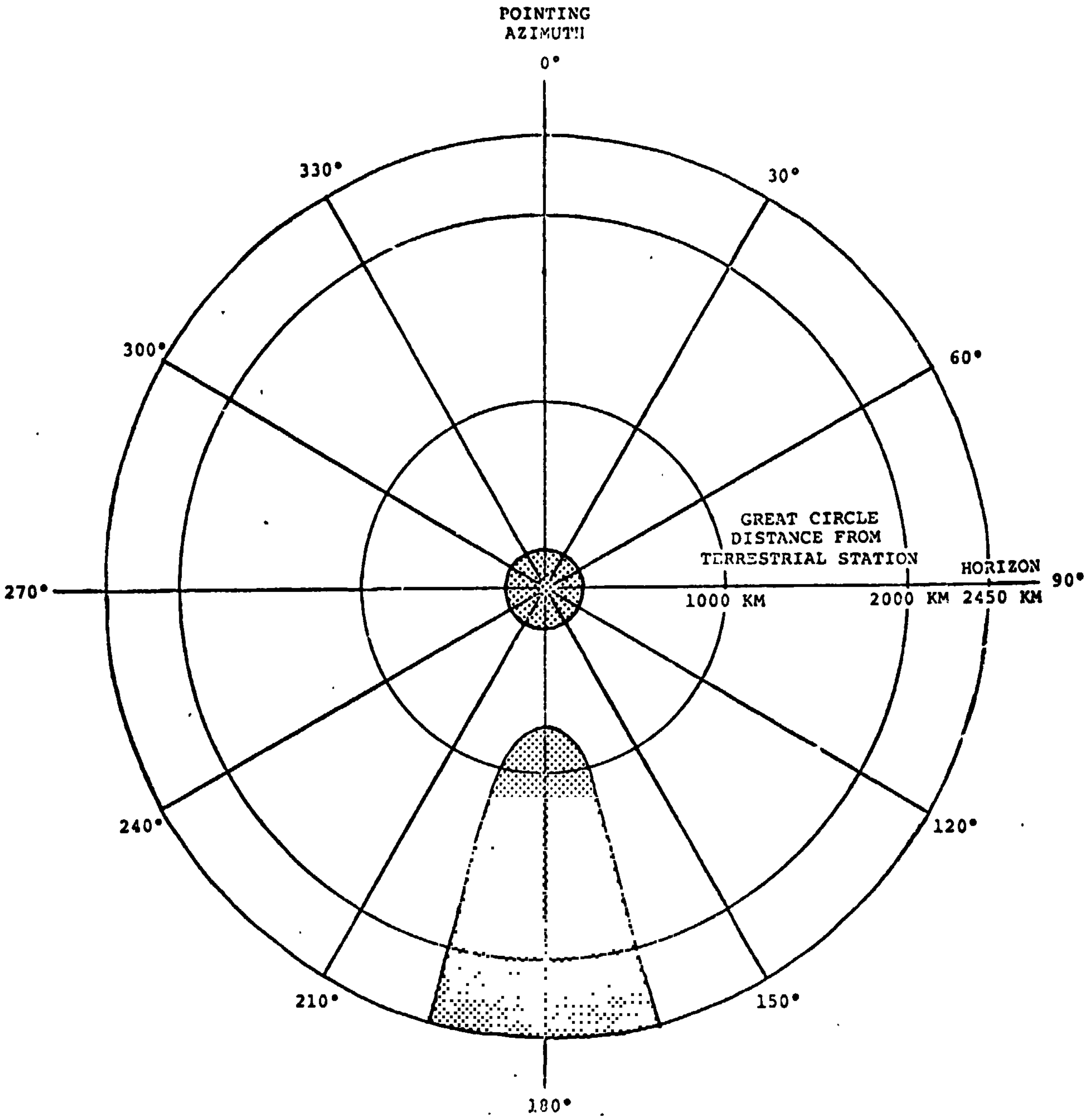



Figure 2-3 Data Loss vs. Number of Terrestrial Transmitters, Aeronautical Radionavigation Service




Note: Shaded areas indicate region where interference and therefore, loss of coverage occurs. Terrestrial station is located in center.

Figure 2-4 Loss of Coverage Area Map Due to Single Emitter - Aeronautical Radionavigation Service

The maximum interference level encountered at the radiometer from a single high power interferor would occur at the horizon as seen from the MLS. The level of this interference would be:

| | | |
|---|---|---|
| Transmitter Power | = | 33 dB(W) |
| Antenna Gain | = | 43 dB(i) |
| Spreading Loss | = | -139 dB($m^2$) |
| Atmospheric Loss | = | -5.6 dB |
| Radiometer Antenna Effective Area (Sidelobe) | = | - 59 dB($m^2$) |
| | | -127.6 dB(W) |

or approximately 32 dB above the -160 dB(W) interference threshold.

Multiple high power MLS will present an even worse situation. Consequently, since indications are that extensive world-wide use is planned, the transmitter population densities, at least in developed countries, will be such that harmful interference will be encountered around the countries concerned.

Sharing on a simultaneous operational basis with either of these two types of MLS, therefore, is considered infeasible.

2.2.2.2 <u>Time Sharing</u>

Due to the requirement for continuous, 24-hour operational use for MLS, no time sharing scheme between passive remote systems and the Aeronautical Radionavigation Service is considered feasible.

### 2.2.3 Conclusions on Sharing with Aeronautical Radionavigation Service

Sharing on a simultaneous operational basis between spaceborne passive microwave sensors of the Earth Exploration Satellite or Space Research Services, and the Fixed and Mobile (15.3-15.35 GHz) and the Aeronautical Radionavigation (15.4-15.5 GHz) Services in the 15.3-15.5 GHz region, is not feasible. Time sharing is generally infeasible with Fixed and Mobile Services, while definitely infeasible with Aeronautical Radionavigation.

Sharing on a simultaneous operational basis between the space passive services and the Radio Astronomy Service in the 15.35-15.4 GHz band is feasible.

# SECTION 3

## FREQUENCY BAND 17.7 - 17.9 GHz

## USER REQUIREMENTS

The primary measurement in this band is water vapor profiling. The water vapor molecules have a rotation absorption line at 22.235 GHz which is pressure broadened in the lower atmosphere to produce measurable absorption at this frequency. Observations at this frequency are required to establish the relative amount of water vapor at intermediate heights in the lower atmosphere.

Water vapor measurements are required over land and water. Observations over land are affected by variations in surface parameters, and must be made with a spatial resolution of less than 2 km in order to reduce the effects of variation within a beamwidth. For a satellite in a 500 km circular orbit, a 2 km resolution requires a beamwidth of 0.2° (4-6 meter antenna depending on pointing angle). The antenna beam passes over a point on the surface in less than 0.2 seconds, requiring an integration time of less than 0.2 seconds.

The range of total precipitable water is 0-7 g/cm$^2$. The accuracy required for estimating the contribution of intermediate atmosphere layers is 0.3 g/km$^2$. To attain this accuracy at 17.7-17.9 GHz, a radiometer sensitivity of 0.2 K is required.

Assuming a total power radiometer with a 1000 K noise temperature, a 0.2 K sensitivity, and a 0.2 second integration time, a bandwidth of 180 MHz is required. A conventional Dicke switched radiometer would required 720 MHz bandwidth.

Water vapor profiles are required twice per day to support weather forecasting services. The update rate is controlled by the input requirements of the numerical forecasting programs operated by the National Weather Service.

## SHARING ANALYSIS

The 17.7-17.9 GHz band is currently allocated to the Fixed, Mobile and Fixed-Satellite Services on a worldwide basis. The latter allocation restricts usage to a space-to-earth link. It is proposed that use for Earth Exploration Service (Passive) and Space Research (Passive) be added, and that Government Fixed and Mobile Service use be deleted. Allocations for private sector Fixed and Mobile Services would remain.

The following sections analyze the sharing potential between passive remote sensors and the Fixed and Mobile Services and the Fixed-Satellite Service (space-to-earth).

### 3.1 Fixed and Mobile Services

A survey of available national and international frequency assignment files indicates that there are no fixed and mobile assignments at this time. It is probable, however, that such use will occur at a future date. Although the Radio Regulations allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 17.7-17.9 GHz band can be expected to make use of digital encoding techniques, rather than the analog technology used for Fixed and Mobile Services below 15 GHz. It is to be expected that the systems installed will consist primarily of either fixed or transportable relay link facilities employing relatively high gain antennas.

### 3.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 17.7-17.9 GHz band are expected to follow guidelines given in CCIR Reports 387-2, 609, and 610. The guidelines and technical specifications are concerned with broadband high capacity digital transmission. In the systems, a high speed digital signal is used to modulate the RF carrier by means of phase-shift-keying. In the United States, the signal is 4-level at 137 MBaud (274 Mbits/sec); in Japan it is 4-level at 200 MBaud (400 Mbits/sec); and in some European countries it is planned to be 4-level at 70 MBaud (140 Mbits/sec).

The actual band allocated for Fixed and Mobile Service use is 17.7-19.7 GHz, and three different channel plans have been developed. One is a plan involving frequency re-use cross polarization techniques for co-channel transmissions, and the others employ interleaved channels. The 200 MHz passive allocation roughly corresponds to the bottom channel of the co-channel plan, and the first one and one-half channels of the interleaved channel plan.

The transmitters used in the 17.7-17.9 GHz band are anticipated to have the following characteristics:

| | |
|---|---|
| Transmitter Power | -13 dB(W) |
| Feeder Loss | - 4 dB |
| Transmitter Antenna Gain | 43.5 dB(i) |
| Transmitted e.i.r.p. | 26.5 dB(W) |

The system design is based on link lengths of 10 km, a fading margin of about 45 dB, and a transmission bandwidth of 220 MHz.

### 3.1.2 Sharing Considerations

#### 3.1.2.1 Simultaneous Operation

The interference level in the main beam of a single interference source would occur at the horizon as seen from a Fixed or Mobile Service transmitter. The level of this interference would be:

| | |
|---|---|
| Transmitter Power | - 13 dB(W) |
| Feeder Loss | - 4 dB |
| Transmitter Antenna Gain | 43.5 dB(i) |
| Spreading Loss | -139 dB |
| Atmospheric Absorption | - 9 dB |
| Radiometer Antenna Effective Area (sidelobe) | - 60 dB($m^2$) |
| | -181.5 dB(W), |

or 21.5 dB below the radiometer interference threshold*. Thus, the radiometer would have to be within the main beam of $\sim$100

*Interference would occur from a direct overhead pass of the interferor. However, the duration of interference is of negligible impact to data measurements in an operational system.

Fixed and Mobile Service transmitters in order for degradation of its function to result. The probability of this occurrence is rather small.

### 3.1.3 Conclusions on Sharing with Fixed and Mobile Services

Sharing on a simultaneous operational basis with the Fixed and Mobile Services in the 17.7-17.9 GHz band is possible.

## 3.2 Fixed-Satellite Service (space-to-earth)

A survey of national and international allocations data indicates that there are no current registrations for the Fixed-Satellite Service (space-to-earth) in this band. It is known, however, that private sector users are planning a domestic satellite system to serve the United States and Possessions. This system, as planned, will operate in the 17.7 to 17.9 GHz band, as opposed to the 17.9 to 19.7 GHz band also allocated to this service. While it is not possible to determine the exact antenna patterns, bandwidth transmitter power and channel plan for the system, it may be assumed that the power used will not cause the power flux density to exceed levels given in CCIR Report 287-2 and its annexes.

### 3.2.1 Technical Characteristics

It is anticipated that the Fixed-Satellite Service down-link operating in the 17.7-17.9 GHz band will have characteristics similar to those of systems designed for the 11 GHz band. These satellites may make use of both spot beam and full-earth coverage antennae. The down-link e.i.r.p., regardless of which antenna is used, should not exceed levels given in CCIR Report 387-2. The maximum allowable PFD in this band is about -104 dB(W/$m^2$/MHz).

Assuming a spot-beam antenna (0.5°), a fixed-satellite transmitter system having the following characteristics would produce the maximum allowable power flux density level:

| | |
|---|---|
| Transmitter Power | 23.4 dB(W) |
| Antenna Gain | 50 dB(i) |
| Transmitter e.i.r.p. | 73.4 dB(W) in a 35 MHz bandwidth |
| Bandwidth Conversion Factor | -15.4 dB(MHz/35 MHz) |
| Transmitter e.i.r.p. spectral density | 58 dB(W/MHz) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Surface Power Flux Density | -104 dB(W/$m^2$/MHz) |

### 3.2.2 Sharing Considerations

#### 3.2.2.1 Simultaneous Operations

The maximum interference level at the radiometer input will be produced when the spacecraft is in the main beam of the fixed-satellite down-link. Two interference paths are possible:

a) Coupling of the down-link signal via the backlobe of the radiometer antenna,

b) Coupling of the down-link signal into the mainlobe of the radiometer antenna by backscattering from the earth's surface.

The interference level for backlobe coupling from a single transponder is computed as follows:*

| | |
|---|---|
| Fixed-Satellite e.i.r.p. | 73.4 dB(W) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Power Flux at Radiometer | - 88.6 dB($W/m^2$) |
| Effective Area of Radiometer Antenna (backlobe) | - 63 dB($m^2$) |
| Received Interference Power | -151.6 dB(W) |

* It is assumed here that the transponder bandwidth is totally contained within the bandwidth of the radiometer.

Thus, backlobe coupling of the signal from a single fixed-satellite down-link does constitute a source of interference to the sensor, since the interference level is 8.4 dB above the sensor threshold of -160 dB(W).

The interference to the radiometer due to the backscattering of one fixed-satellite down-link signal from the earth is computed as follows:

| | |
|---|---|
| Fixed-Satellite e.i.r.p. | 73.4 dB(W) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Power Flux at Earth Surface | - 88.6 dB($W/m^2$) |
| Reflectivity Factor (50% Loss) | - 3 dB |
| Power Reflected from Earth (per square meter) | - 91.6 dB($W/m^2$) |
| Surface Area Within Mainlobe of Radiometer | + 73 dB($m^2$) |
| Reflected Signal e.i.r.p. | - 18.6 dB(W) |
| Spreading Loss | -125 dB($m^{-2}$) |
| Power Flux at Radiometer Antenna | -143.6 dB($W/m^2$) |
| Radiometer Antenna Effective Area | +10.5 dB($m^2$) |
| Received Interference Power | -133.1 dB(W) |

Thus, backscattering of a single fixed-satellite down-link signal will result in reception by the radiometer of interference 26.9 dB in excess of its threshold of -160 dB(W). This would effectively preclude use of the frequency band for radiometric purposes whenever within about 1.9° of the fixed-satellite main beam.

3.2.2.2 Time Sharing

No information is currently available concerning the operating schedule for the proposed Fixed-Satellite Service transmissions. It cannot be assumed, however, that these systems would be inoperative during the late night-early morning hours. Consequently, time sharing with the Fixed-Satellite Service in this band is generally considered infeasible.

3.2.3 Conclusions on Sharing with Fixed-Satellite Service

Due to anticipated large volume common carrier traffic served by fixed-satellite systems in this band, sharing on a simultaneous operational basis between spaceborne microwave sensors and the Fixed-Satellite Service is infeasible. Time sharing with this Service does not seem to be a viable alternative.

# SECTION 4

## FREQUENCY BAND 19.7 - 19.9 GHz

## USER REQUIREMENTS

Measurements are required at 19.7 to 19.9 GHz to support water and land observations of surface phenomena. Observations in this frequency band are also required for cloud, rain, and water vapor measurements. For most phenomena, a radiometer sensitivity of 1 K is sufficient. The highest resolution application is water vapor profiling. For water vapor measurements, a spatial resolution of 2 km is required. For a satellite in a 500 km circular orbit, the beamwidth for a 2 km surface resolution is $0.2^{\circ}$ and this requires a 4-5 meter antenna, depending upon pointing angle. Since a point on the surface is within the antenna beam for less than 0.2 seconds, the maximum integration time is 0.2 seconds.

The range of total precipitable water is 0-7 $g/cm^2$. The accuracy required for estimating the contribution of an intermediate atmospheric layer is 0.3 $g/cm^2$. To accomplish this at 19.7-19.9 GHz, a radiometer sensitivity of 0.2 K is required (See Part A for sensitivity curves.)

Assuming a total power radiometer with a 1000 K noise temperature, a 0.2 K sensitivity and a 0.2 second integration time, a bandwidth of 180 MHz is required. A conventional Dicke switched radiometer would require a 720 MHz bandwidth.

Water vapor profiles are required twice per day to support weather forecasting services. This collection rate is controlled by the input requirements for the numerical forecasting programs operated by the National Weather Service. Rain measurements, on the other hand, may require observations as often as once per hour for input into numerical forecasting programs.

## SHARING ANALYSIS

The 19.7-19.9 GHz band is currently allocated to the Fixed-Satellite Service on a worldwide basis. This allocation is restricted to space-to-earth links. In addition, Footnote 4C`E indicates that the band may be used for fixed and mobile operations in Japan.

The following sections analyze the sharing potential between passive remote sensors and the Fixed and Mobile Services in Japan and the Fixed-Satellite Service (space-to-earth) in Regions 1, 2 and 3.

### 4.1 Fixed and Mobile Services

A survey of available national and international assignment files indicates that there are no Fixed and Mobile assignments at this time. It is probable, however, that such use will occur at a future date. It is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 19.7-19.9 GHz band can be expected to make use of digital encoding techniques, rather than the analog technology used for Fixed and Mobile Services below 15 GHz. It is to be expected that the systems installed will consist primarily of either fixed or transportable relay link facilities employing relatively high gain antennas.

### 4.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 19.7-19.9 GHz band are expected to follow guidelines given in CCIR Reports 387-2, 609, and 610. The guidelines and technical specifications are concerned with broadband, high capacity digital transmission. In such systems, a high speed digital signal is used to modulate the RF carrier by means of phase-shift-keying. In the United States, the signal is 4-level at 137 MBaud (274 Mbits/sec); in Japan 4-level at 200 MBaud (400 Mbits/sec); and in some European countries a 4-level at 70 MBaud (140 Mbits/sec) is planned.

The transmitters used in the 19.7-19.9 GHz band are anticipated to have the following characteristics:

| | |
|---|---|
| Transmitter Power | -13 dB(W) |
| Feeder Loss | - 4 dB |
| Transmitter Antenna Gain | 43.5 dB(i) |
| Transmitted e.i.r.p. | 26.5 dB(W) |

The system design is based on link lengths of 10 km, a fading margin of about 45 dB, and a transmission bandwidth of 220 MHz

### 4.1.2 Sharing Considerations

#### 4.1.2.1 Simultaneous Operation

The interference level in the main beam of a single interference source would occur at the horizon as seen from a Fixed or Mobile Service transmitter. The level of this interference would be:

| | |
|---|---|
| Transmitter Power | - 13 dB(W) |
| Feeder Loss | - 4 dB |
| Transmitter Antenna Gain | 43.5 dB(i) |
| Spreading Loss | -139 dB |
| Atmospheric Absorption | - 17 dB |
| Radiometer Antenna Effective Area (sidelobe) | -61.4 dB($m^2$) |
| | -191.4 dB(W) |

or 31.4 dB below the radiometer interference threshold of -160 dB(W).* Thus, the radiometer would have to be within the main beam of 1000 Fixed and Mobile Service transmitters in order to reach the interference threshold. The probability of this occurence is negligible.

4.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the expected low e.i.r.p.'s employed by digital relay link facilities in the 19.7-19.9 GHz band, and the fact that the current allocation for such services apply only to the country of Japan, sharing on a simultaneous operational basis is considered feasible.

4.2 Fixed-Satellite Service (space-to-earth)

A survey of national and international allocations data indicates that there are no current registrations for the Fixed-Satellite Service (space-to-earth) in this band. No plans have been identified concerning proposed use of this band either by the U.S. or other countries.

* Interference would occur to the radiometer from a direct overhead pass of the interferor. However, duration of interference is of negligible impact to data measurements in an operational system.

ORIGINAL PAGE IS OF POOR QUALITY

In all probability, the design of 19.7-19.9 GHz systems would be similar to those proposed for the similar allocation at 17.7-19.7 GHz. It is not possible to determine the exact antenna patterns, bandwidth transmitter power and channel plan for such systems. However, it may be assumed that the power used will not cause the power flux density to exceed levels given in CCIR Report 387-2 and its annexes, since part of the Fixed-Satellite band is shared with the Fixed and Mobile Services.

### 4.2.1 Technical Characteristics

It is anticipated that the Fixed-Satellite Service down-link operating in the 19.7-19.9 GHz band will have characteristics similar to those of systems designed for the 11 GHz band. These satellites may make use of both spot beam and full-earth coverage antennae. The down-link e.i.r.p., regardless of which antenna is utilized, should not exceed levels given in CCIR Report 387-2.

Assuming a spot-beam antenna (0.5°), a fixed-satellite transmitter system having the following characteristics would produce the maximum allowable power flux density level:

| | |
|---|---|
| Transmitter Power | 23.4 dB(W) |
| Antenna Gain | 50 dB(i) |
| Transmitter e.i.r.p. | 73.4 dB(W) in a 35 MHz bandwidth |
| Bandwidth Conversion Factor | -15.4 dB (MHz/35 MHz) |
| Transmitter e.i.r.p. spectral density | 58 dB (W/MHz) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Surface Power Flux Density | -104 dB($W/m^2$/MHz) |

### 4.2.2 Sharing Considerations

#### 4.2.2.1 Simultaneous Operations

The maximum interference level at the radiometer input will be produced when the radiometer is in the main beam of the fixed-satellite down-link. Two interference paths are possible:

a) Coupling of the down-link signal via the backlobe of the radiometer antenna.

b) Coupling of the down-link signal into the mainlobe of the radiometer antenna by backscattering from the earth's surface.

The interference level for backlobe coupling from a single transponder is computed as follows:*

| | |
|---|---|
| Fixed-Satellite e.i.r.p. | 73.4 dB(W) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Power Flux at Radiometer | -88.6 dB($W/m^2$) |
| Effective Area of Radiometer Antenna (backlobe) | -64.4 dB($m^2$) |
| Received Interference Power | -153.0 dB(W) |

* It is assumed here that the transponder bandwidth is totally contained within the bandwidth of the radiometer.

Thus, backlobe coupling of the signal from a single fixed-satellite down-link constitutes a source of interference to the sensor, since the interference level is 7.0 dB above the sensor interference threshold of -160 dB(W).

The interference to the radiometer due to the backscattering from the earth of one fixed-satellite down-link signal is computed as follows:

| | |
|---|---|
| Fixed-Satellite e.i.r.p. | 73.dB(W) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Power Flux at Earth Surface | -88.6 dB($W/m^2$) |
| Reflectivity Factor (50% Loss) | - 3 dB |
| Power Reflected from Earth (per square meter) | - 91.6 dB($W/m^2$) |
| Surface Area Within Mainlobe or Radiometer | + 73 dB($m^2$) |
| Reflected Signal e.i.r.p. | - 18.6 dB(W) |
| Spreading Loss | -125 dB($m^{-2}$) |
| Power Flux at Radiometer Antenna | -143.6 dB($W/m^2$) |
| Radiometer Antenna Effective Area | 9.6 dB($m^2$) |
| Received Interference Power | -134 dB(W) |

Thus, backscattering of a single fixed-satellite down-link signal will result in reception by the radiometer of interference 26 dB in excess of its threshold of -160 dB(W). This would effectively preclude use of the frequency band for radiometric purposes whenever the radiometer is within about 1.7° of the main beam of the fixed-satellite.

4.2.2.2 Time Sharing

No information is currently available concerning the operating schedule for the proposed Fixed-Satellite Service transmissions. It cannot be assumed, however, that these systems would be inoperative during the late night-early morning hours. Consequently, time sharing with the Fixed-Satellite Service in this band is generally considered infeasible.

4.2.3 Conclusions on Sharing with Fixed-Satellite Service (space-to-earth)

Considering that use of the 17.7-19.7 Fixed-Satellite Service allocations is expected to be primarily for domestic, high volume traffic and that if the band is used, numerous fixed-satellites would be employed world wide, sharing on a simultaneous operational or time basis in the 19.7-19.9 GHz band is considered infeasible.

# SECTION 5

# FREQUENCY BAND 21.0 - 21.2 GHz

## USER REQUIREMENTS

The primary measurement in this band is water vapor profiling. The water vapor molecules have a rotation absorption line at 22.234 GHz which is pressure broadened in the lower atmosphere to produce measurable absorption at this frequency. Observations at this frequency are required to establish the relative amount of water vapor at intermediate heights in the lower atmosphere.

Water vapor measurements are required over land and water. Measurements over land are affected by variations in surface parameters, and observations with a 2 km spatial resolution are required in order to reduce the effects of variations within a beamwidth. For a satellite in a 500 km circular orbit, a 2 km beam size on the surface requires a beamwidth of 0.2° (4-6 meter antenna depending upon pointing angle). The antenna beam passes over a point on the surface in less than 0.2 seconds, requiring an integration time of less than 0.2 seconds.

The range of total precipitable water is 0-7 $g/cm^2$. The accuracy required to estimate the contribution at intermediate heights is 0.3 $g/cm^2$. To attain this accuracy at this frequency, a radiometer sensitivity of 0.2 K is required.

Assuming a total power radiometer with a 1000 K noise temperature, a 0.2 K sensitivity and a 0.2 second integration time, a bandwidth of 180 MHz is required. A conventional Dicke switched radiometer would require a bandwidth of 720 MHz.

Water vapor profiles are required twice per day to support weather forecasting services. The update rate is controlled by the input requirements of the numerical forecast programs operated by the National Weather Service.

## SHARING ANALYSIS

The 21.0-21.2 GHz band is currently allocated to the Fixed-Satellite Service (space-to-earth). This allocation includes all of the 20.2-21.2 GHz spectral region. Additionally, there exists a Mobile-Satellite Service (space-to-earth) proposed allocation in the 20.2-21.2 GHz band.

The following analysis considers the potential for sharing between passive spaceborne sensors and both the Fixed- and Mobile-Satellite Service (space-to-earth).

### 5.1 Fixed- and Mobile-Satellite Service (space-to-earth)

Current U. S. and international frequency assignment data files indicate that there are presently no assignments in the 21.0-21.2 GHz spectral region for fixed- or mobile-satellite oepration. Indications are, however, this band may be used in the future for government communications systems. In the U. S. and internationally it is estimated that high volume domestic fixed-satellite operations in this frequency region will be confined to the 17.7-19.7 GHz band.

### 5.1.1 Technical Characteristics

Data is not generally available as to the technical operational characteristics of fixed- and mobile-satellite systems in this band. However, some baseline characteristics can lead, with proper assumptions, to an estimate of the required satellite e.i.r.p. (assuming spread-spectrum techniques) in order to meet the link budget as follows:

$$\text{Required e.i.r.p.} = C_o/N_o + L_s - A_r + k + T_R$$

where: $C_o/N_o$ = earth station required carrier-to-noise density ratio (+ 10 dB)

$L_s$ = spreading loss (162 dB($m^2$))

$A_r$ = earth station receiver effective area (2 dB($m^2$))

$T_R$ = earth station receiver noise temperature (30 dB(K))

$k$ = Boltzmann's constant (-228.6 dB(W/K/Hz))

Therefore, the required fixed- or mobile-satellite e.i.r.p. is:

$$= +10 + 162 - 2 - 228.6 + 30$$

$$\cong -29 \text{ dB(W/Hz)}$$

5.1.2 Sharing Considerations

5.1.2.1 Simultaneous Operations

The interference level produced by the above assumed fixed- and mobile-satellite operations may occur from a reflected path in the main beam of the radiometer, or from a direct link through the backlobe of the radiometer antenna.

The level of interference produced from reflected energy is calculated below:

| | |
|---|---|
| Mobile-satellite e.i.r.p. | = - 29 dB(W/Hz) |
| Atmospheric Attenuation* | = -0.6 dB |
| Spreading loss to earth | = -162 dB($m^{-2}$) |
| Reflection Coefficient | = - 3 dB |
| Atmospheric attenuation | = -0.3 dB |
| Spreading loss to 500 km orbit | = -125 dB($m^{-2}$) |
| Area in view to radiometer main beam | = + 66 dB($m^2$) |
| Effective area of radiometer antenna (main beam) | = + 8 dB($m^2$) |
| Interference level | = -245.9 dB(W/Hz), |

or -163.4 dB(W) in a 180 MHz bandwidth of the radiometer. This is 3.4 dB below the interference threshold of -160 dB(W).

*Assuming 30° elevation of earth station receiver.

Interference entering the radiometer via the backlobe constitutes a lower level as seen by the following:

| | | |
|---|---|---|
| Mobile-satellite e.i.r.p. | = | - 29 dB(W/Hz) |
| Spreading loss | = | -162 dB($m^{-2}$) |
| Radiometer antenna effective area (backlobe) | = | - 65 |
| | | -256 dB(W/Hz), |

or -173 dB(W) in a 180 MHz radiometer bandwidth. This is 13 dB below the radiometer interference threshold.

Current indications are that a maximum of 3 mobile-satellites would be employed for world coverage. At most, the radiometer would be visible to two of these satellites, and the interference level could be 3 dB higher than -163 dB(W) or -160 dB(W), which is equal to the radiometer interference threshold.

### 5.1.3 Conclusions on Sharing with Fixed- and Mobile-Satellite Services

Considering that the interference encountered is expected only to be marginally harmful and that the duty cycles of these systems will not necessarily be 100%, it is concluded that simultaneous operational sharing with the Fixed- and Mobile-Satellite Services in this band is feasible.

Consequently, a primary, co-equal allocation between these services is feasible. The criteria for the passive services to share with fixed- and mobile-satellites is that the fixed- and mobile-satellites do not exceed a PFD at the surface of the earth of -155 dB($W/m^2$/4 kHz), or equivalently a -29 dB(W/Hz) e.i.r.p.

# SECTION 6

## FREQUENCY BAND 22.1 - 22.5 GHz

## USER REQUIREMENTS

The primary application in this frequency is water vapor measurements. Observations of water vapor are required to support land surface, sea surface, cloud, and rain measurements made at other frequencies. The water vapor molecules have a rotation absorption line in this band at 22.235 GHz. Observations are required at this frequency to measure total precipitable water.

Water vapor measurements are required over land and water. Measurements over land are affected by variations in surface parameters, and observations with a 2 km spatial resolution are required in order to reduce the effect of variations within a beamwidth. For a satellite in a 500 km circular orbit, a 2 km size on the surface requires a beamwidth of 0.2° (4-6 meter antenna, depending upon pointing angle). The antenna beam passes over a point on the surface in less than 0.2 seconds, imposing a maximum integration time of less than 0.2 seconds.

The range of total precipitable water is 0-7 g/cm$^2$ and an accuracy of 0.3 g/cm$^2$ is required. To obtain this accuracy, a radiometer sensitivity of 0.4 K is required.

Assuming a total power radiometer with a 1000 K noise temperature, a 0.4 K sensitivity and a 0.2 second integration time, a 45 MHz bandwidth is required. A 9 beam position, 18 km swath could be imaged utilizing 400 MHz.

Water vapor profiles are required twice per day to support weather forecasting services. The update rate is controlled by the input requirements of the numerical forecast programs operated by the National Weather Service. Update rates required to support rain and cloud measurements may be as often as once per hour.

## SHARING ANALYSIS

The 22.1-22.5 GHz band is currently allocated to the Fixed and Mobile Services. It is proposed that these services be deleted, and that the band be shared by three services - Space Research (passive), Earth Exploration Service (passive), and the Radio Astronory Service. Additionally, non-government proposals include the addition of an allocation for the General Radio Service (i.e., Citizens Band Radio).

Since Radio Astronomy and Space Research (passive) can inherently share with another passive service, the following sections analyze the sharing potential between the Earth Exploration Satellite Service (passive), the Space Research Service (passive) and the Fixed and Mobile Services. An analysis of sharing with Citizens Band radio systems is not included because it is not probable that, within the next 20 years, technology will permit systems at 22 GHz to be competitive with the cost of equipment at the current 27 MHz, or the proposed 220 and 900 MHz frequency bands.

## 6.1 Fixed and Mobile Services

A survey of available national and international assignment data files indicates that there are no Fixed and Mobile Service assignments for other than experimental use. It is possible, however, that such use will occur at a future date. The Radio Regulations allow fixed and mobile systems in all three regions, and it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service developments in the 22.1-22.5 GHz band can be expected to make use of digitally encoded techniques, rather than analog technology used below about 15 GHz. It is expected that the systems installed will consist primarily of either fixed or transportable relay link facilities, employing relatively high gain antennas.

### 6.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 22.1-22.5 GHz band are expected to follow guidelines given in CCIR Reports 387-2, 609, and 610. The guidelines and technical specifications are concerned with broadband high capacity digital transmissions. In the systems, a high speed digital signal is used to modulate the RF carrier by means of phase-shift-keying. In the United States, the signal is 4-level at 137 M-baud (274 Mbits/sec); in Japan it is 4-level at 200 M-band (400 Mbits/sec) and in some European countries it is planned to be 4-level at 70 M-baud (140 MBits/sec).

The transmitters used in the 22.1-22.5 GHz band are anticipated to have the following characteristics:

| | | |
|---|---|---|
| Transmitter power | = -13 | dB(W) |
| Feeder Ioss | = -4 | dB |
| Transmitter Antenna Gain | = 43.5 | dB(i) |
| Transmitted e.i.r.p. | = 26.5 | dB(W) |

The system design is based on link lengths of 10 km, a fading margin of about 45 dB, and a transmission bandwidth of 220 MHz.

### 6.1.2 Sharing Considerations

#### 6.1.2.1 Simultaneous Operation

The interference level in the main beam of a single interference source would occur at the horizon as seen from a Fixed or Mobile Service transmitter. The level of this interference would be:

| | | |
|---|---|---|
| Transmitter Power | = - 13 | dB(W) |
| Feeder Loss | = - 4 | dB |
| Antenna Gain | = 43.5 | dB(i) |
| Spreading Loss | = -139 | dB($m^{-2}$) |
| Atmospheric Loss | = - 33 | dB |
| Radiometer Antenna Effective Area (sidelobe) | = - 62 | dB($m^2$) |
| | -207.5 | dB(W) |

ORIGINAL PAGE IS OF POOR QUALITY

or 54.5 dB below the radiometer interference threshold of -157 dB(W).* Thus, the radiometer would have to be in the main beams of ~100,000 Fixed and Mobile transmitters. The probability of this occurrence is negligible.

### 6.1.3 Conclusions on Sharing with Fixed and Mobile Services

Sharing on a simultaneous operational basis between the Fixed and Mobile Services and the Earth Exploration Satellite Service (passive) is feasible due to the low required e.i.r.p. of digitally encoded fixed and mobile systems in the 22.1-22.5 GHz band.

Consequently, a primary, co-equal allocation between the space passive services and the Fixed and Mobile Services is feasible. The criteria for sharing with digital fixed and mobile systems is that these systems conform to the specifications of CCIR Reports 387-2, 609, and 610.

*Interference would occur from a direct overhead pass of the interferor. However, the duration of interference are of negligible impact to data measurements in an operational system.

# SECTION 7

# FREQUENCY BAND 23.6 - 24.0 GHz

## USER REQUIREMENTS

The primary measurement in this band is water vapor profiling. The water vapor molecules have a rotation absorption line at 22.234 GHz which is pressure broadened in the lower atmosphere to produce measurable absorption at this frequency. Observations at this frequency are required to establish the relative amount of water vapor at intermediate heights in the lower atmosphere.

Water vapor measurements are required over land and water. Measurements over land are affected by variations in surface parameters, and observations with a 2 km spatial resolution are required in order to reduce the effects of variations within a beamwidth. For a satellite in a 500 km circular orbit, a 2 km beam size on the surface requires a beamwidth of 0.2° (4-6 meter antenna, depending upon pointing angle). The antenna beam passes over a point on the surface in less than 0.2 seconds, integration time of less than 0.2 seconds.

The range of total precipitable water is 0-7 g/cm$^2$. The accuracy required to estimate the contribution at intermediate heights is 0.3 g/cm$^2$. To attain this accuracy at this frequency, a radiometer sensitivity of 0.2 K is required. (See Part A for sensitivity curves.)

Assuming a total power radiometer with a 1000 K noise temperature, a 0.2 K sensitivity and a 0.2 second integration time, a bandwidth of 180 MHz is required. A conventional Dicke switched radiometer would require a bandwidth of 720 MHz.

Water vapor profiles are required twice per day to support weather forecasting services. The update rate is controlled by the input requirements of the numerical forecast programs operated by the National Weather Service.

## SHARING ANALYSIS

The 23.6-24.0 GHz band is currently allocated to the Radio Astronomy Service. It is proposed that the band be shared by three services - Space Research (Passive), Earth Exploration Service (Passive), and the Radio Astronomy Service. Since the Radio Astronomy and Space Research (passive) Services can inherently share with another passive service, frequency sharing is feasible.

Consequently, a primary, co-equal allocation is feasible.

# SECTION 8

# FREQUENCY BAND 31.3 - 31.8 GHz

## USER REQUIREMENTS

The primary measurements in this band are water vapor and snow and ice morphology. Measurement around the pressure broadened water vapor line at 22.234 GHz can provide information on water vapor content at different altitudes in the atmosphere. This band, while having some water vapor and oxygen attenuation, is the lowest attenuation region above 20 GHz. Consequently, this band is also extremely desirable for measurement of surface phenomena.

The spacial resolution requirements for all phenomena in this band is on the order of 2 km. For a satellite in a 500 km circular orbit, a 2 km beam size on the surface requires a beamwidth of 0.2° (4-6 m antenna). Since the antenna beam traverses a point on the surface in less than 0.2 seconds, the integration time must be less than 0.2 seconds.

The most constraining measurement from a bandwidth requirement viewpoint is water vapor measurements. For water vapor, the measurement range of total precipitable water desired is 0-7 $g/cm^2$. The accuracy required to estimate the contribution at intermediate heights is 0.3 $g/cm^2$. To attain this accuracy, a radiometer sensitivity of 0.2 K is required (see Part A for sensitivity curves).

Assuming a total power radiometer with a 1200 K system noise temperature, a 0.2 K sensitivity and a 0.2 second integration time, a bandwidth of 180 MHz is required.  A conventional Dicke radiometer would require 720 MHz bandwidth.

Water vapor profiles are required twice per day to support weather forecasting services of the National Weather Service. Surface phenomena data are required once per day.

## SHARING ANALYSIS

The 31.3-31.5 GHz band is currently allocated in Regions 1, 2, and 3 to the Radio Astronomy Service. However, Footnote 412A specifies that in Bulgaria, Cuba, Hungary, Poland, the United Arab Republic, Romania, Czechoslovakia and the U.S.S.R., the band is also allocated to the Fixed and Mobile Services. The 31.5-31.8 GHz band is currently allocated on a primary basis to the Space Research Service and on a secondary basis to the Fixed and Mobile Services.

Since passive spaceborne sensors and the Radio Astronomy Service can inherently share this frequency band, this analysis is concerned with sharing with the Fixed and Mobile Services.

### 8.1 Fixed and Mobile Services

A survey of available national and international frequency assignment files indicate there are presently no fixed or mobile assignments at this time. It is possible, however, that the countries will make use of the band. It is anticipated that this use will be confined to highly developed, popula[illegible] areas, rather than in the more sparsely populated and oceanic [illegible]

Fixed and Mobile Services development in the 3[illegible] GHz band can be expected to make use of digital encodi[illegible]ques rather than the analog technology used in Fixed and Mobile Services below 15 GHz. It is expected that the systems installed will consist primarily of either fixed or transportable relay link facilities employing relatively high gain antennas.

### 8.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 31.3-31.8 GHz band are expected to follow guidelines given in CCIR Reports 387-2, 609, and 610. The guidelines and technical specifications are concerned with broadband high capacity digital transmission. In the systems, a high speed digital signal is used to modulate the RF carrier by means of phase-shift-keying. In the United States, the signal is 4-level at 137 M-Baud (274 Mbits/sec); in Japan 4-level at 200 M-baud (400 Mbits/sec); and in some European countries 4-level at 70 M-Baud (140 Mbits/sec) is planned.

The technical characteristics of a 31.3-31.5 GHz fixed or mobile system can be estimated by examining the characteristics of proposed operating systems in the 17.7-19.7 GHz band. Such systems employ links of about 10 km in length, and have the following operational parameters:

| | | |
|---|---|---|
| Transmitter Power | = | -13 dB(W) |
| Feeder Loss | = | - 4 dB |
| Antenna Gain | = | 43.5 dB(i) |
| Transmit e.i.r.p. | = | 26.5 dB(W) |

Assuming that 10 km links are utilized at 31.3-31.8 GHz, the transmit e.i.r.p. requirement for such a link can be computed by adding a factor to compensate for the increased frequency, assuming a constant gain antenna at the receiver, and including a factor to allow for increased atmospheric absorption at 31 GHz.

A 31 GHz system e.i.r.p. requirement is computed as follows:

| | | |
|---|---|---|
| Baseline e.i.r.p. | = | 26.5 dB(W) |
| Frequency Factor | = | 4.9 dB |
| Absorption Factor | = | 0.3 dB |
| 31 GHz e.i.r.p. | = | 31.7 dB(W) |

Based on operational considerations (e.g., antenna pointing accuracy, size, weight, transmitter technology, etc.), it is expected that the 32 dB(W) system e.i.r.p. would be generated differently for Fixed and Mobile Services. Mobile systems, at a given frequency, tend to have smaller antennas, but larger powers, than fixed systems. The estimated design parameters are given below:

| | FIXED | MOBILE |
|---|---|---|
| Transmitter Power | -11.8 dB(W) | - 6.8 dB(W) |
| Antenna Gain | 43.5 dB(i) | 38.5 dB(i) |
| System e.i.r.p. | 31.7 dB(W) | 31.7 dB(W) |

## 8.1.2 Sharing Considerations

### 8.1.2.1 Simultaneous Operation

The maximum interference level for a single interference source will be produced when the radiometer is in the Fixed or Mobile main beam. This occurs at the horizon, as seen from a fixed or mobile transmitter. The level of this interference would be:

| | | |
|---|---|---|
| Transmitter Power | = | - 6.8 dB(W)* |
| Antenna Gain | = | 38.5 dB(i) |
| Spreading Loss | = | -139 dB($m^{-2}$) |
| Atmospheric Absorption | = | - 15.2 dB |
| Radiometer Antenna Effective Area (Sidelobe) | = | - 65.4 dB($m^2$) |
| | | -187.9 dB(W) |

or 28 dB below the radiometer interference threshold of -160 dB(W).** Thus, the radiometer would have to be within the main beam of 600-700 Fixed and Mobile Service transmitters in order for the interference threshold to be exceeded. The probability of this occurrence is negligible.

* Typical mobile system.

** Interference would occur to the radiometer from a direct overhead pass of the interference source. However, the duration of interference is considered of negligible impact to data measurements in operational systems.

### 8.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the low e.i.r.p.'s expected to be employed by fixed and mobile systems in this band, and, that these systems would be confined to the countries listed in Radio Regulations' footnote 412A, sharing on a simultaneous operational basis, with the Fixed and Mobile Services in the 31.3-31.8 GHz band is considered feasible.

Consequently, a primary, co-equal allocation between these services is feasible. The criteria for sharing with the Fixed and Mobile Services is that these systems conform to the general specifications of CCIR Reports 387-2, 609 and 610.

# SECTION 9

# FREQUENCY BAND 36.0 - 37.0 GHz

## USER REQUIREMENTS

The primary measurements in this frequency band are land and sea surface parameters, rain, and clouds. Observations to support rain and cloud measurements over land require a beamwidth of 0.1° (4-6 meter antenna), to permit a surface resolution of 1 km. This spatial resolution is required to reduce the effects of the spatial variation in surface parameters within a beamwidth. Since the antenna beam passes over a point on the surface in less than 0.1 seconds, the integration time must be less than 0.1 seconds.

The range of equivalent rain rates at this frequency is 0-10 mm/hr. For over-land application, the discrimination of rain from surface parameters, which produce nearly the same brightness temperature, requires measurements at two polarizations. These measurements must be made with a sensitivity of 1.0 K, to separate the two effects, and to provide a measurement accuracy of 5 percent.

Assuming a Dicke switched radiometer with a 2400 system noise temperature, a 1.0 K sensitivity and a 0.1 second integration time, a bandwidth of 230 MHz is required. In order to image a swath, multiple 4-beam position scanning antennas could be utilized. In a multibeam, limited scanning mode, integration time would be 25 msec and require a bandwidth of 920 MHz.

Observations in this frequency band are required to support a number of measurements having update rates ranging from once per week to once per hour. For the support of weather forecast services, observations must be made twice per day.

# SHARING ANALYSIS

The 36-37 GHz band is currently allocated to the Fixed and Mobile Services. It is proposed that these services be deleted, and that the band be shared by four services - Space Research (passive), Earth Exploration Service (passive), and the Fixed-Satellite and Mobile-Satellite Services. In Cuba, Eastern Europe, and the USSR, portions of the band are also allocated to the Radio Astronomy Service.

The following sections analyze the sharing potential between passive remote sensors and the Fixed and Mobile Services, and the Fixed- and Mobile-Satellite Services.

## 9.1 Fixed and Mobile Services

A survey of available national and international assignment data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile service development in the 36-37 GHz band can be expected to make use of digital encoding techniques, rather than the analog technology used for Fixed and Mobile Services below 15 GHz. It is to be expected that the systems installed will consist primarily of either fixed or transportable relay link facilities employing relatively high gain antennas.

### 9.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 36-37 GHz band are expected to follow guidelines given in CCIR Reports 387-2, 609, and 610. The guidelines and technical specifications are concerned with broadband high capacity digital transmission. In the systems, a high speed digital signal is used to modulate the RF carrier by means of phase-shift-keying. In the United States, the signal is 4-level at 137 M-Baud (274 Mbits/sec); in Japan it is 4-level at 200 M-Baud (400 Mbits/sec); and in some European countries it is planned to be 4-level at 70 M-Baud (140 Mbits/sec).

The technical characteristics of a 36 GHz fixed or mobile system can be estimated by examining the characteristics of proposed operating systems in the 17.7-19.7 GHz band. Such systems employ links of about 10 km in length, and have the following operational parameters:

| | | | |
|---|---|---|---|
| Transmitter Power | = | -13 | dB(W) |
| Feeder Loss | = | - 4 | dB |
| Antenna Gain | = | 43.5 | dB(i) |
| Transmit e.i.r.p. | = | 26.5 | dB(W) |

Assuming that 10 km links are utilized at 36 GHz, the transmit e.i.r.p. requirement for such a link can be computed by adding a factor to compensate for the increased frequency, assuming a constant gain antenna at the receiver, and including a factor to allow for increased atmospheric absorption at 36 GHz.

A 36 GHz system e.i.r.p. requirement is computed as follows:

| | | | |
|---|---|---|---|
| Baseline e.i.r.p. | = | 26.5 | dB(W) |
| Frequency Factor | = | 6.2 | dB |
| Absorption Factor | = | 0.3 | dB |
| 36 GHz e.i.r.p. | | 33 | dB(W) |

Based on operational considerations (e.g., antenna pointing accuracy, size, weight, transmitter technology, etc.), it is expected that the 33 dB(W) system e.i.r.p. would be generated differently for Fixed and Mobile Services. Mobile systems, at a given frequency, tend to have smaller antennas, but larger powers, than fixed systems. The estimated design parameters are given below:

| | FIXED | MOBILE |
|---|---|---|
| Transmitter Power | - 6.5 dB(W) | - 1.5 dB(W) |
| Feeder Loss | - 4 dB | - 4 dB |
| Antenna Gain | 43.5 dB(i) | 38.5 dB(i) |
| System e.i.r.p. | 33 dB(W) | 33 dB(W) |

### 9.1.2 Sharing Considerations

#### 9.1.2.1 Simultaneous Operation

The interference level in the main beam of a single interference source would occur at the horizon as seen from a Fixed or Mobile transmitter. The level of this interference would be:

| | | | |
|---|---|---|---|
| Transmitter Power | = | - 1.5 | dB(W)* |
| Feeder Loss | = | - 4 | dB |
| Antenna Gain | = | 38.5 | dB(i) |
| Spreading Loss | = | -139 | dB($m^{-2}$) |
| Atmospheric Absorption | = | - 18 | dB |
| Radiometer Antenna Effective Area (Sidelobe) | = | - 67 | dB($m^2$) |
| | | -191 | dB(W) |

*Typical mobile system.

or 45 dB below the radiometer interference threshold of -146 dB(W)**. Thus, the radiometer would have to be within the main beam of ~20,000 Fixed and Mobile Service transmitters in order for degradation of its function to result. The probability of this occurrence is very small.

### 9.1.3 Conclusions on Sharing with Fixed and Mobile Services

Sharing on a simultaneous operational basis between spaceborne passive microwave sensors and the Fixed and Mobile in the 36-37 GHz band is feasible.

Consequently, the space passive services can be allocated on a primary, co-equal basis.

The criteria for the space passive services to share are that Fixed and Mobile Service emissions must conform to the specifications in CCIR Reports 387-2, 609, and 610.

### 9.2 Fixed- and Mobile-Satellite Services

A survey of national and international allocation data files indicates there are no current registrations for other than experimental and developmental use. However, the U.S.

**Interference would occur from a direct overhead pass of the interferor. However, the duration of interference is of negligible impact to data measurements in an operational system.

ORIGINAL PAGE IS
OF POOR QUALITY

Government apparently plans to use the band for satellite communication systems having both fixed and mobile earth terminals. Little technical information is available, but it is known that world-wide usage is contemplated, with on the order of 30 earth terminals. The channel plan, however, and frequency dispersion characteristics of these systems are not known. The analysis contained herein is adapted from known technical characteristics of a similar government system which operates at 8 GHz. The down-link design of the 36 GHz system is known to differ radically from the 8 GHz system, in that it is a broadband spread-spectrum system. The down-link parameters have been derived from earth station receiver characteristics.

### 9.2.1 Technical Characteristics

It is anticipated that government satellite up-links operating in the 36-37 GHz band will have characteristics similar to those of the system presently operating at 8 GHz. The transponders may be equipped with both spotbeam as well as full coverage antennas. Up-link transmitter powers must be adequate to drive the transponder when a full coverage antenna is used. It is estimated that the fixed- and mobile-satellite up-link parameters will be as follows:

| | FIXED | MOBILE |
|---|---|---|
| Transmitter Power | 29 dB(W) | 41 dB(W) |
| Antenna Gain | 57 dB(i) | 45 dB(i) |
| Transmit e.i.r.p. | 86 dB(W) | 86 dB(W) |

Data is not available relative to the technical operational characteristics of fixed- and mobile-satellite system down-links. However, some baseline characteristics can lead, with proper assumptions, to an estimate of the required satellite e.i.r.p. (assuming spread-spectrum techniques) in order to meet the link budget as follows:

$$\text{Required e.i.r.p.} = C_o/N_o + L_s - A_r + k + T_R$$

where: $C_o/N_o$ = earth station required carrier-to-noise density ratio (+ 10 dB)

$L_s$ = spreading loss (162 dB($m^2$))

$A_r$ = earth station receiver effective area (-3 dB($m^2$))

$T_R$ = earth station receiver noise temperature (33 dB(K))

$k$ = Boltzmann's constant (-228.6 dB(W/K/Hz))

Therefore, the required mobile-satellite e.i.r.p. is:

$$\text{Required e.i.r.p.} = +10 + 162 + 3 - 228.6 + 33$$

$$= -21 \text{ dB(W/Hz)}$$

ORIGINAL PAGE IS
OF POOR QUALITY

### 9.2.2 Sharing Considerations

#### 9.2.2.1 Simultaneous Operations

The maximum interference level at the radiometer from a single interferor will occur when the radiometer is in the main beam of a fixed or mobile earth station. Assuming a 30° elevation angle of the earth station, this interference level would be:

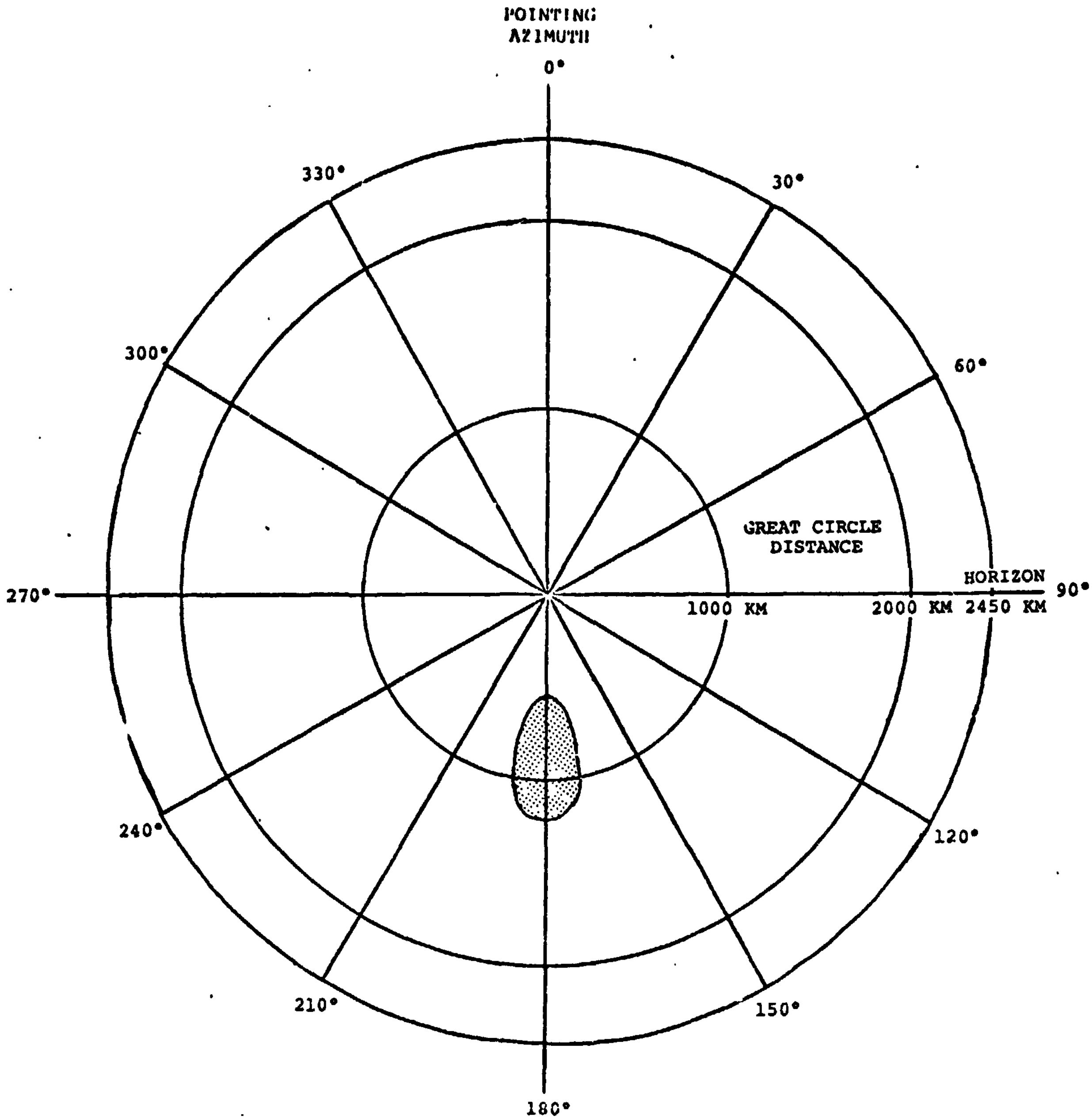
| | | |
|---|---|---|
| Transmitter Power | = | 41 dB(W)* |
| Antenna Gain | = | 45 dB(i) |
| Spreading Loss | = | -130 dB($m^{-2}$) (30° elevation angle) |
| Atmospheric Absorption | = | -0.5 dB |
| Radiometer Antenna Effective Area (Sidelobe) | = | - 67 dB($m^2$) |
| | | -111.5 dB(W), |

or 34.5 dB above the radiometer interference threshold of -146 dB(W).

Figure 9-1 illustrates the loss of coverage area resulting from operation of a single Mobile-Satellite Service earth station. The analysis is based on the Gain-Range Quotient program analysis procedure described in Appendix I of this volume. This area corresponds to approximately 2% of the total visibility sphere around the earth station. The analysis assumes a 30° elevation of the earth station antenna directed at the geostationary orbit.

---

*Typical mobile earth stations.




Note: Shaded areas indicate region where interference and therefore, loss of coverage occurs. Earth station is located in center.

Figure 9-1 Loss of Coverage Area Map, Mobile-Satellite Service

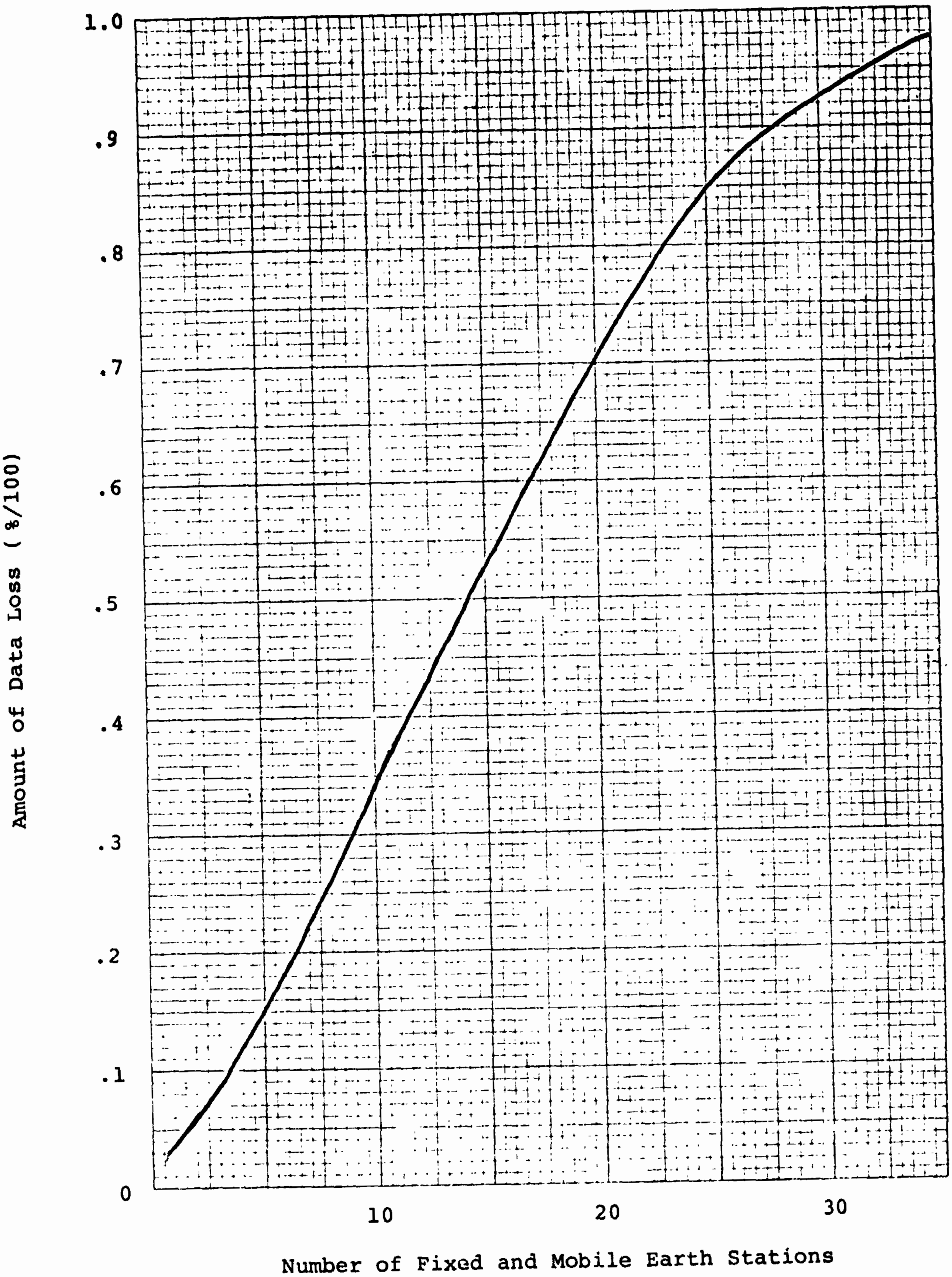
Figure 9-2 presents the results of the Random Interference Analysis Program (see Appendix II) relating the amount of data loss to the number of fixed and mobile earth stations visible to the radiometer. As can be seen, large loss of data would occur if 15 earth stations are simultaneously in view. It is possible that the spatial density of earth terminals would not be this great. Additionally, many of the earth stations may be shipborne, and therefore would not be fixed interference sources.

The interference level produced by fixed- and mobile-satellite down-link operations may occur from a reflected path in the main beam of the radiometer, or from a direct link through the backlobe of the radiometer antenna.

The level of interference produced from reflected energy is calculated below:

| | | |
|---|---|---|
| Fixed- or mobile-satellite e.i.r.p. | = - 21 | dB(W/Hz) |
| Atmospheric Attenuation | = - 0.3 | dB |
| Spreading loss to earth | = -162 | dB($m^{-2}$) |
| Reflection Coefficient | = - 3 | dB |
| Atmospheric attenuation | = - 0.3 | dB |
| Spreading loss to 500 km orbit | = -125 | dB($m^{-2}$) |
| Area in view to radiometer mainbeam | = + 57.7 | dB($m^2$) |
| Effective area of radiometer antenna (mainbeam) | = + 12 | dB($m^2$) |
| Interference level | = -241.9 | dB(W/Hz) |

or -152.3 dB(W) in a 920 MHz bandwidth of the radiometer, or 6.3 dB.




ORIGINAL PAGE IS OF POOR QUALITY

Figure 9-2 Data Loss vs. Number of Fixed and Mobile Earth Stations below the radiometer interference threshold of -152 dB(W).

Interference entering the radiometer via the backlobe constitutes a lower level as seen by the following:

| | |
|---|---|
| Mobile satellite e.i.r.p. | = - 21 dB(W/Hz) |
| Spreading loss | = -162 dB($m^{-2}$) |
| Radiometer antenna effective area (backlobe) | = - 70 |
| | -252 dB(W/Hz) |

or -166.4 dB(W) in a 920 MHz radiometer bandwidth, or 17.4 dB below the radiometer interference threshold.

The dominant mode of down-link interference is by reflection from the earth. This interference will not affect sensor operation unless the radiometer is simultaneously in the main beam of more than four spacecraft. The probability of this occurrence is very small. Therefore simultaneous sharing with the down-link is feasible.

### 13.2.3 Conclusions on Sharing with Fixed- and Mobile-Satellite Services

Simultaneous operation between spaceborne passive microwave sensors and the Fixed- and Mobile-Satellite Services in the 36-37 GHz band is considered marginally feasible, depending on the number of earth stations visible to the radiometer.

Thus, the space services could possibly be allocated on a primary, co-equal basis assuming low population densities. The criteria for sharing would then be:

- Fixed and Mobile-Satellite (down-link) - The PFD at the surface of the earth must not exceed $-147$ dB(W/$m^2$/4 kHz), or equivalently $-21$ dB(W/Hz) e.i.r.p.

- Fixed and Mobile-Satellite (up-link) - The earth stations e.i.r.p. must not exceed +86 dBW.

# SECTION 10

## FREQUENCY BAND 50.2 - 50.4 GHz

## USER REQUIREMENTS

The principal measurements to be made in this band are simultaneous observations of various emissions of molecular oxygen required to construct temperature profiles for the lower atmosphere. The requested band is relatively broad in order to encompass a number of the closely space oxygen ($O_2$) lines from the 50-70 GHz complex of lines. The band was chosen to allow observation on a number of closely space channels within the band, each providing different altitude information.

Temperature profiles are required over all types of land and water surfaces. A relatively small, 10 km or less, resolution element on the surface provides a number ot overland observation sites that may be used without severe contamination by the variation of surface emission within a beam. Observations in this band will require supporting observations in the low attenuation frequency bands at 37 and 90 GHz in order to provide estimates of the surface, rain, and cloud effects. For a satellite in a 500 km orbit, a 10 km resolution requires the use of a 0.2 meter antenna, depending on pointing angle. Since the antenna beam traverses a point on the surface in less than 1.0 seconds, the integration time must be less than 1.0 seconds.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is desired. The integration time is determined, not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate from. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and an 84 km vertical scan, a 1 second integration time is required.

The multifrequency temperature profiling observations and an accuracy of better than 0.3 K to provide temperature estimates within an accuracy of 1 to 2°C. For a Dicke radiometer, with a system noise temperature of 2,300 K, a 0.3 K sensitivity and 1 second integration time, the minimum bandwidth required per measurement channel is 235 MHz. Multiple 235 MHz channels in numerous bands between 50-70 GHz are required to provide temperature sounding approximately every 2 km in altitude.

Temperature profile measurements are needed to support numerical weather forecasting services and observations are required twice per day.

## SHARING ANALYSIS

The 50.2-50.4 GHz band is currently allocated to the Fixed-Satellite Service (earth-to-space) in Regions 1, 2, and 3. It has been proposed that in a portion of the band (50.4-50.5 GHz) allocations for Fixed and Mobile Services and the Mobile Satellite Service (earth-to-space) be added in Regions 1, 2, and 3.

The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed- and Mobile - Satellite Service (earth-to-space) and the Fixed and Mobile Services.

### 10.1 Fixed and Mobile Services

A survey of available national and international assignment data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 50.2-50.4 GHz band can be expected to make use of digital encoding techniques, rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 10.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 50.2-50.4 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-2, 609, and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the carrier by means of phase shift RF keying.

The key factor influencing the design and implementation of radio links in the 50-60 GHz region are the amounts of absorption due to oxygen and water vapor as well as the large attenuations due to rain. These factors limit radio link hops to much smaller lengths than conventionally employed at frequencies below 15 GHz. It is anticipated that the allocation for Fixed and Mobile Services in the 50.2-50.5 GHz band will be used for intra-city communications network with hop lengths of 1 km or less.

The following calculation of required fixed and mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C + FM - G_t + 10 \log(4\pi R^2) - A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-91.8 dB(W))

$G_t$ = transmit antenna gain (43.5 dB(i))

$R$ = hop length (1 km)

FM = fade margin (45 dB)

$A_R$ = receiver antenna effective area

or a required transmitter power of -7.34 dB(W).

### 10.1.2 Sharing Considerations

#### 10.1.2.1 Simultaneous Operations

Due to the high levels of atmospheric absorption in the horizontal path, interference in the main beam of a fixed or mobile system will not occur.

Normal radiometer operations in the 50.2-50.4 GHz band are for nadir-looking observations. Thus, the only time the radiometer will experience interference is when there is a direct overhead pass and the interferor is in the main beam of the nadir-looking radiometer antenna. The level of this interference would be:

*Based on assumed receiver noise figure of 15 dB.

| | | |
|---|---|---|
| Transmitter Power | = | - 7.34 dB(W) |
| Antenna Gain (backlobe) | = | - 10 dB(i) |
| Spreading Loss | = | -125 dB($m^2$) |
| Atmospheric Absorption | = | - 1.5 dB |
| Radiometer Antenna Effective Area (mainbeam) | = | - 9.5 dB(W) |
| | | -153.3 dB(W) |

or 4.7 dB above radiometer interference threshold.

Considering that the radiometer antenna beamwidth results in a resolution element at the surface of the earth of 5 km, ~5 interfering sources may be simultaneously in view to the radiometer. This would result in approximately 7 dB(W) more interference or approximately 12 dB above the interference threshold of -158 dB(W).

It is expected that use of fixed line-of-sight links at 50-60 GHz will be primarily in large metropolitan areas. Typically, these areas span 30-80 km. It will be over these areas that collection of data from passive remote sensors will be interfered with. However, since data surrounding each metropolitan area will be interference free and valid, and since a great deal of interpolation across interference regions of this size may be performed, it is considered that loss of direct overhead measurements of metropolitan areas is not harmful as such.

### 10.1.3 Conclusions on Sharing with the Fixed and Mobile Services

Sharing on a simultaneous operational basis between the Fixed and Mobile Services and the Earth Exploration Satellite Service (passive) is feasible due to the low required e.i.r.p. of digitally encoded fixed and mobile systems in the 50.2-50.5 GHz band.

Consequently, a primary, co-equal allocation between the space passive services and the Fixed and Mobile Services is feasible. The criteria for sharing with digital fixed and mobile systems is that these systems conform to the specifications of CCIR Reports 387-2, 609 and 610.

## 10.2 Fixed and Mobile Satellite Services

A survey of available national and international assignment data files indicates that there are no Fixed or Mobile Satellite Service assignments at this time. It is possible, however, that such use will occur at a future date.

It is anticipated that these operations in the 50.2-50.5 GHz band will make use of multiple feed high gain antennas resulting in coverage of national areas by a number of spot beams. A similar design philosophy would be employed for both up and down links, to enable frequency reuse in non-adjacent beam patterns. Since the beam patterns would each serve a relatively small area, a large number of earth stations is necessary if the total coverage is to include an extensive service area. At least one earth station would be required for each spot beam.

## 10.2.1 Technical Characteristics

The technical characteristics of the as yet undeveloped Fixed-and Mobile-Satellite Services are expected to follow the same basic philosophy proposed for the Fixed-Satellite Services in lower allocated bands. This philosophy implies the use of relatively high gain antennas at both the spacecraft and earth stations resulting in coverage of a large area by a number of spot beams, rather than by a single broad beam.

Due to the high atmosphere absorption in this frequency band, high antenna gains are desirable, however, the tracking problems involved with extremely narrow, high gain antenna beams limit the maximum useful gain to about 55 dB.

If a transmitter output power were 30 dB(W), a 30 dB fade margin could be achieved assuming a 15 dB receiver noise figure. The link calculation leading to these results are as follows:

| | |
|---|---|
| Transmitter Output Power | 30 dB(W) |
| Transmitter Antenna Gain | 65 dB(i) |
| Transmitted e.i.r.p. | 95 dB(W) |
| Spreading Loss | -163 dB($m^{-2}$) |
| Atmospheric Absorption | - 9.2 dB($m^{-2}$) |
| Effective Area of Receiving Antenna | + 9.5 dB($m^2$) |
| Received Power | - 67.7 dB(W) |

| | |
|---|---|
| **Noise Power** | **-113.1 dB(W)** |
| **C/N Ratio** | **45.4 dB** |
| **Required C/N Ratio** | **15.0 dB** |
| **Link Fade Margin** | **30.4 dB** |

**A fade margin of 30 dB is considered reasonable and, hence, a potential system in this band would likely have powers and gains as derived above. However, a power of 30 dB(W) would completely exhaust the available power budget of current communication satellites.**

### 10.2.2 Sharing Considerations

#### 10.2.2.1 Simultaneous Operation

Normal radiometer operations in the 50.2 - 50.4 GHz band are for nadir looking observations. The radiometer antenna gain will be 46 dB(i) and the radiometer susceptible interference level is -158 dB(W).

An average pointing angle for mid-latitude terrestrial station antennas is 30° above the horizon. If the radiometer bearing spacecraft passes through the main beam of the terrestrial station coupling is via the side lobes of the radiometer antenna and the interference level is computed as follows:

ORIGINAL PAGE IS
OF POOR QUALITY

| | |
|---|---|
| Earth Station e.i.r.p. | 95 dB(W) |
| Spreading Loss | -130.0 dB($m^{-2}$) |
| Atmospheric Absorption (30° elevation path) | -3.2 dB |
| Effective Area of Radiometer Antenna (Sidelobe) | -69.5 dB($m^2$) |
| Received Interference Power | -107.7 dB(W) |

which is 50.3 dB above the interference threshold of -158 dB(W).

Thus, severe interference will result whenever the spacecraft is located within the main beam of the terrestrial station if this station is operating with an antenna pointing angle above the horizon of at least several degrees. The loss of coverage area for a single station corresponds to about 0.24% of the visibility sphere as viewed from the earth station. The interference level decreases to below the threshold value when the radiometer is located more than 5° off the main beam of the earth station.

The Random Interference Analysis Program was utilized to simulate the multi-inteferor interference enviornment based on the anticipated system parameters. Figure 10-1 presents the results of this analysis. The figure relates the probability of data loss versus the number of earth station transmitters simultaneously operating and visible to the radiometer.

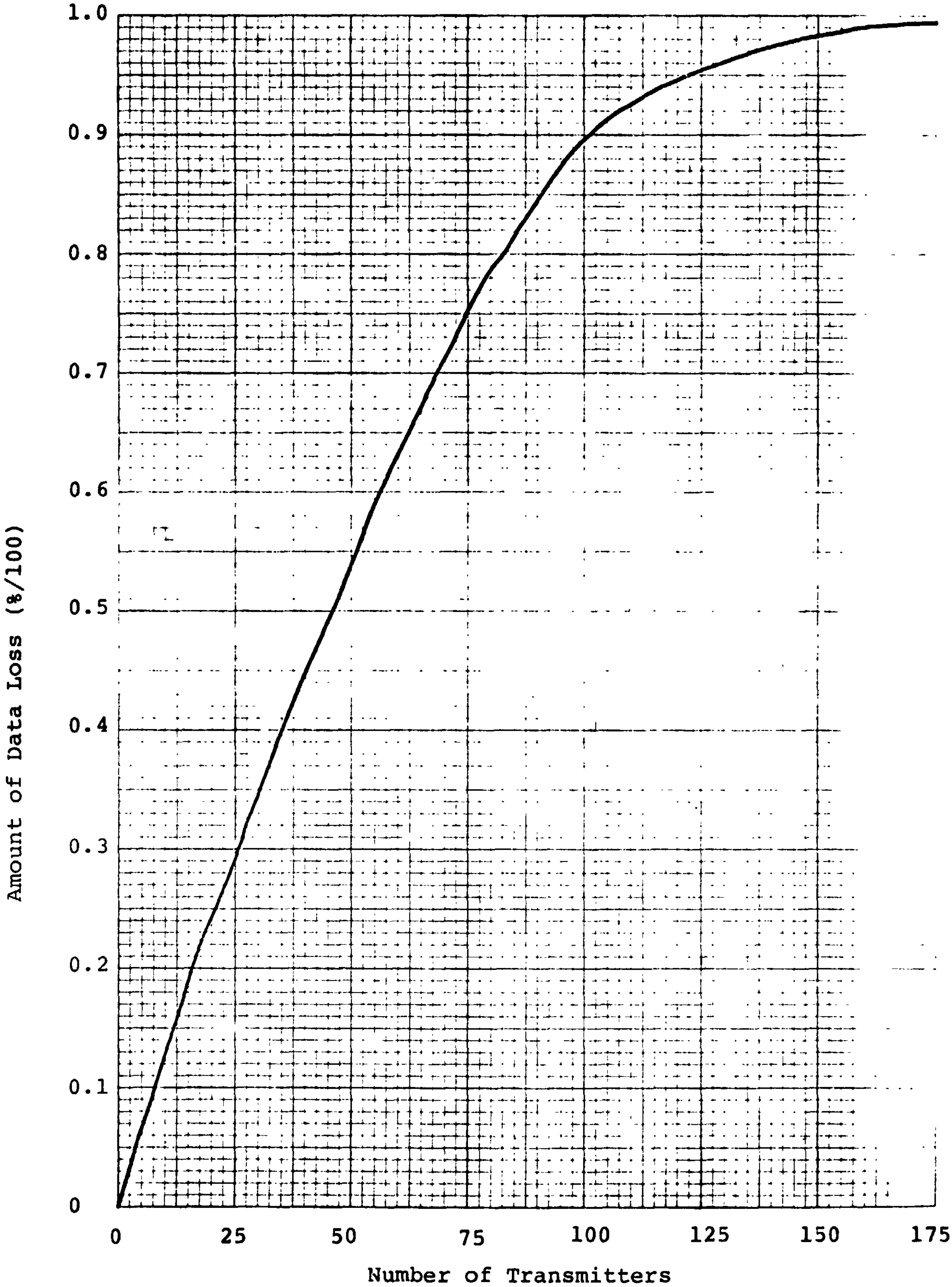



Figure 10-1 Data Loss vs Number of Terrestrial Transmitters, Fixed- and Mobile-Satellite Service

Although little is known concerning the projected extent of usage of this band by the Fixed- and Mobile-Satellite Services, large amount of data would be lost if more than 50 of these stations were simultaneously in view of the radiometer.

Thus, if a system were installed in the U.S. and the satellite employed 50 spot beams to cover the land area of the contiguous 48 states, and one earth station were located in each beam footprint then sharing with this service on a simultaneous basis would be infeasible.

It is, however, quite unlikely that such a service would be implemented within the forseeable future, since the expense would be rather high and an intensive development effort would be needed for the spacecraft design (for the simultaneous operation of 50 transponders with sufficient power to permit reliable communications approximately 1/4 megawatt of on board power would be required)

Simultaneous sharing with a system employing a small number of earth stations is feasible because of the small loss of coverage area associated with each station.

### 10.2.3 Conclusions on Sharing with the Fixed- and Mobile-Satellite Services

Simultaneous sharing with Fixed- and Mobile- Satellite Services in the 50.2-50.4 GHz frequency band is feasible only if the number of earth stations simultaneously in view is small, that is less than 10.

# SECTION 11

# FREQUENCY BAND 51.4 - 59.0 GHz

## USER REQUIREMENTS

The principal measurements to be made in this band are simultaneous observations of various emissions of molecular oxygen required to construct temperature profiles for the lower atmosphere. The requested band is relatively broad in order to encompass a number of the closely space oxygen ($O_2$) lines from the 50-70 GHz complex of lines. The band was chosen to allow observation on a number of closely space channels within the band, each providing different altitude information.

Temperature profiles are required over all types of land and water surfaces. A relatively small, 10 km or less, resolution element on the surface provides a number of overland observation sites that may be used without severe contamination by the variation of surface emission within a beam. Observations in this band will require supporting observations in the low attenuation frequency bands at 37 and 90 GHz in order to provide estimates of the surface, rain, and cloud effects. For a satellite in a 500 km orbit, a 10 km resolution requires the use of a 0.2 meter antenna, depending on pointing angle. Since the antenna beam traverses a point on the surface in less than 1.0 seconds, the integration time must be less than 1.0 seconds.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is desired. The integration time is determined, not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate from. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and an 84 km vertical scan, a 1 second integration time is required.

The multifrequency temperature profiling observations need an accuracy of better than 0.3 K to provide temperature estmiates within an accuracy of 1 to 2°C. For a Dicke radiometer, with a system noise temperature of 2,300 K, a 0.3 K sensitivity and 1 second integration time, the minimum bandwidth required per measurement channel is 235 MHz. Multiple 235 MHz channels in numerous bands between 50-70 GHz are required to provide temperature sounding approximately every 2 km in altitude.

Temperature profile measurements are needed to support numerical weather forecasting services and observations are required twice per day.

## SHARING ANALYSIS

Portions of the 51.4-59.0 GHz band are currently or proposed to be allocated to the Inter-Satellite Service, Fixed and Mobile Service and the space passive services. The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed, Mobile and Inter-Satellite Services.

### 11.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 51.4-59.0 GHz band can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 11.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 51.4-59.0 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors driving the design and implementation of radio links in the 50-60 GHz region are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances than conventionally employed at frequencies below 15 GHz. It is estimated that the allocation for Fixed and Mobile Services in the 51.4-59.0 GHz band will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C - G_t - 1/4\pi R^2 - F.M. + A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-91.8 dB(W))

$G_t$ = transmit antenna gain (43.5 dB(i))

$R$ = hop length (1 km)

F.M. = fade margin (45 dB)

$A_R$ = receive antenna effective area

or a required transmitter power of -6.0 dB(W).

### 11.1.2 Sharing Considerations

#### 11.1.2.1 Simultaneous Operations

Due to the high levels of atmospheric absorption in the horizontal path, interference in the main beam of a fixed or mobile system will not occur.

Due again to large atmospheric absorption in the vertical path, interference will not occur to the radiometer when its antenna is directed at the interferor as seen from the following:

| | | | |
|---|---|---|---|
| Transmitter Power | = | - 6.0 | dB(W) |
| Antenna Gain | = | - 10 | dB(i) |
| Spreading Loss | = | -125 | dB($m^{-2}$) |
| Atmospheric Absorption | = | -100 | dB |
| Radiometer Antenna Effective Area (main beam) | = | - 13.6 | dB($m^2$) |
| | | -254.6 | dB(W) |

or well below the radiometer interference level of -157 dB(W).

*Based on assumed receiver noise figure of 15 dB.

### 11.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the low e.i.r.p.'s envisioned to be employed by digital fixed and mobile systems and the high atmospheric absorption which occurs in this band, sharing on a simultaneous operational basis is feasible.

## 11.2 Inter-Satellite Service

The use of radio communication links between space stations is basically an alternative to employing multiple earth station antenna systems or multiple-hop terrestrial circuits.

Although there has generally been little study as to optimum system configuration (frequency, bandwidth, power, link geometry, etc.), the possible links are:

1) geostationary-to-geostationary satellite links;
2) geostationary-to-low orbit satellite links, and
3) low orbit-to-geostationary links.

Localized areas of interference could be encountered by a spaceborne sensor when: 1) passing through the down-link tracking beam of the geostationary satellite, 2) in close proximity to an up-link transmitting low-orbiting satellite, or 3) pointing (for a limb sounder) directly at the geostationary satellite. Cumulative side lobe interference from multiple inter-satellites is not expected to be an important factor.

The following sections discuss the potential for sharing between Inter-Satellite Service links and passive remote sensors operating in the frequency band. The analyses presented herein are based on worst case conditions in order to address the maximum levels of potential interference.

### 11.2.1 Geostationary-to-Geostationary Link

The only available documentation concerning geostationary-to-geostationary inter-satellite links has been developed by Study Group 4 of the CCIR. This documentation basically discusses communications between spacecraft less than about 30° apart in the geostationary orbit and indicates that the optimum spacing for non-tracking geostationary-to-geostationary links is frequency dependent. Study Group 4 is studying the use of non-tracking communication services below 50 GHz. Therefore, the technical characteristics upon which the underlying sharing analysis is based result from a hypothetical system model which is presented in Annex IV.

The only interference modes, as discussed in Annex IV, that are of concern in this link are for a limb sounder main beam coupling to either the geostationary satellite side lobes or main beam.

11.2.1.1 Technical Characteristics

Several types of geostationary-to-geostationary inter-satellite systems are discussed in Annex IV. The only interference situation occurs for a limb-sounding radiometer operating within the transmit frequency band of a geostationary-to-geostationary inter-satellite system with the following characteristics:

| | | |
|---|---|---|
| Required predetection C/N | = | 10.0 dB |
| Post detection C/N | = | 20 dB |
| Receiver noise figure | = | 15 dB |
| Transmit Bandwidth | = | 2 GHz |
| Inter-satellite antenna gains | = | 64.4 dB(i) |
| Transmit power | = | 11.5 dB(W) |
| Inter-satellite spacing | = | 161.2° |

The geostationary satellites utilize 4m antennas which are capable of tracking the receiving geostationary spacecraft.

11.2.1.2 Sharing Considerations

11.2.1.2.1 Simultaneous Operations

In order to completely describe potential interference to spaceborne radiometers from geostationary-to-geostationary satellite links, a detailed dynamic sharing model is required. However, an upper bound on the potential for large area

interference situations can be determined under assumed worst case conditions. The assumed interference geometry presented herein includes geostationary satellite spacing of 161° (beam grazing a 500 km orbital altitude) and a spaceborne radiometer orbit inclination and pointing angle (limb sounder) of the antenna such that main beam to main beam antenna coupling could exist. Although it is not expected that this interference situation will ever occur, the following calculation presents an upper bound on potential interference.

| | |
|---|---|
| Transmit e.i.r.p. | = + 75.8 dB(W) |
| Bandwidth conversion factor | = - 9.3 (235 MHz/2 GHz) |
| Spreading loss | = -163.3 dB |
| Radiometer effective area (main beam & limb sounder) | = + 8.2 |
| | - 88.6 dB(W) |

or 68.4 dB(W) above the interference threshold of -157 dB(W).

Due to the very narrow antenna beamwidth employed by both the spaceborne radiometers and geostationary satellites, large isolation from interference may be obtained by small changes in relative orientation of the two satellites. This upper bound calculation indicates that no more than 3% (see Appendix IV) of the radiometer orbital sphere would be lost to data measurements regardless of the radiometer orbital configuration. This upper

bound loss would occur only for inter-satellite systems separated by approximately 160° of the geostationary arc. For systems separated less than 70° of the geostationary arc, no interference could be received by the radiometer even when its antenna is directed at the geostationary satellite. For satellite spacings of between 70 and 161°, much less than 3% of the orbital sphere would be lost to data measurements.

### 11.2.2 Geostationary to Low Orbit Link

A search of national and international data files, as well as published technical documentation has revealed no current utilization or plans for future development of a geostationary to low orbit link in the Inter-Satellite Service in this frequency band. The sharing analysis presented herein is, therefore, based on a theoretical estimate of the technical parameters which would be required to achieve communications on such a link.

#### 11.2.2.1 Technical Characteristics

The technical characteristics of geostationary to low orbit links in the Inter-Satellite Service have been estimated using an assumed design employing spread spectrum techniques. The spread spectrum system design parameters are as follows:

| | |
|---|---|
| Required predetection carrier to noise ratio | = 10 dB |
| Receiver noise figure | = 15 dB |
| Transmission bandwidth | = 2 GHz |
| Geostationary satellite antenna gain | = 60 dB(i) |
| Low orbit satellite antenna gain | = 50 dB(i) |

The geostationary satellite transmitter power required to permit communications over the link can be computed by the following relationship:

$$P_t = N + 10 \text{ dB} - G_t - A_R + L$$

where: $N$ = Receiver noise power

$G_t$ = Transmitting antenna gain

$A_R$ = Receiving antenna effective area

$L$ = Spreading loss.

For the above system parameters the required transmitter power is 23.7 dB(W).

11.2.2.2 Sharing Considerations

11.2.2.2.1 Simultaneous Operations

The worst case interference geometry would be main beam-to-main beam coupling between the geostationary and the radiometer antennas when limb sounders are employed. This interference will occur when the geostationary satellite is tracking a low-orbit satellite that is in the limb of the earth. The interference level in this instance is computed as follows:

| | |
|---|---|
| Transmitted e.i.r.p. | 83.7 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Spreading loss | -163.0 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | + 8.2 dB($m^2$) |
| Received interference | - 80.4 dB(W) |

or 76.6 dB above the interference threshold of -157 dB(W). For nadir looking radiometers, the interference would be 2.4 dB below the interference level. This interference situation is of such infrequent occurrence, that the loss of radiometer data would be negligible.

A limb sounding radiometer will experience interference whenever its main beam is directed at the side lobes of the geostationary satellite as seen from the following calculations:

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB(i) gain) | 23.7 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Spreading loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | + 8.2 dB($m^2$) |
| | -140.4 dB(W) |

or 16.6 dB above the interference threshold.

Although this level does constitute interference to the radiometer, the length of time that interference would be above threshold is of negligible impact to data measurements. Additionally, the value calculated is conservative in that no consideration is given to potential atmospheric attenuation at the earth's limb.

Another mode of interference couplings, which could be more significant, would occur whenever the radiometer passes through the main beam of a geostationary-to-low-orbit link. In this instance, coupling of the signal would be via the side lobe of the radiometer antenna, and the resulting interference level (identical for both limb and nadir radiometers) is computed as follows:

| | | |
|---|---|---|
| Transmitted e.i.r.p. | 83.7 | dB(W) |
| Bandwidth conversion factor | - 9.3 | dB (235 MHz/2 GHz) |
| Spreading loss | -163 | dB($m^{-2}$) |
| Radiometer antenna effective area (side lobe) | - 70.8 | dB($m^2$) |
| Received interference power | -159.4 | dB(W) |

or 2.4 dB below the radiometer interference threshold of -157 dB(W).

Consequently, for the interference geometries presented above, no significant interference will be experienced by the radiometer due to the geostationary to low orbit link.

ORIGINAL PAGE IS
OF POOR QUALITY

### 11.2.3 Low Orbit to Geostationary Link

There is currently no available technical documentation concerning development of a low orbit to geostationary links in the Inter-Satellite Service in this frequency band. It may be assumed however, that the link design philosophy would be similar to the geostationary to low orbit link described in paragraph 11.2.2.

#### 11.2.3.1 Technical Characteristics

The technical characteristics of the low orbit to geostationary link have been estimated using an assumed design employing spread spectrum techniques. The design parameters employed are given in paragraph 11.2.3.1. Using the link calculation given therein, the required transmitter power is determined to be 23.7 dB(W).

#### 11.2.2.1 Sharing Considerations

##### 11.2.3.2.1 Simultaneous Operations

The amount of interference received by the radiometer from a transmitter located on a low orbit spacecraft is highly dependent upon the distance between the two spacecraft, which can vary from tens to thousands of kilometers. The spreading loss therefore may fluctuate as much as 60 to 70 dB.

The likelihood of main beam-to-main beam coupling between the two spacecraft is negligibly remote. The radiometer spacecraft would have to be directly above the low orbit communication satellites and in juxtaposition with the geostationary satellites.

The only potential for large areas of interference would be from side lobe to side lobe coupling since the gain at most of the $4\pi$ steradians around the antenna is at 0 dB(i) or lower.

The following calculation determines the separation distance required between two spacecraft in order that side lobe coupling does not cause interference.

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB gain) | 23.7 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Radiometer antenna effective area (side lobe) | -56.8 dB($m^2$) |
| Interference threshold | -(-157 dB(W)) |
| Required spreading loss | 114.6 dB($m^{-2}$) |

or a distance of 152 km.

In order for the spacecraft to pass within this distance, the orbital altitude of the two spacecraft must be within 152 kilometers. If the two spacecraft are to remain within this distance of each other for a significant amount of time, the basic orbital parameters must be nearly identical. It is highly improbable that two spacecraft would be launched into such similar orbits unless it were a matter of design.

ORIGINAL PAGE IS
OF POOR QUALITY

## 11.2.4 Conclusions on Sharing with Inter-Satellite Service

Interference would be encountered by passive spaceborne radiometers from operations in the Inter-Satellite Service only when high gain coupling exists between the antennas of the two systems. Although it has not been possible to determine the probability of this occurrence quantitatively (this would involve a complex dynamic computer model) it appears that it would be insignificant and the duration of interference would be of negligible impact to data measurements. An extreme worst case model indicates a maximum data loss of less than 3%. More realistic consideration would indicate that this value is high by possibly several orders of magnitude.

Additionally, even a 3% loss of data in this band would not impair operational radiometric measurements since measurements are being made of large scale atmospherics.

Conseqeuntly, sharing on a simultaneous operational basis between passive spaceborne sensors and these two services is considered feasible, and a primary, co-equal allocation is feasible.

# SECTION 12

## FREQUENCY BAND 64.0 - 65.0 GHz

## USER REQUIREMENTS

The principal measurements to be made in this band are simultaneous observations of various emissions of molecular oxygen required to construct temperature profiles for the lower atmosphere. The requested band is relatively broad in order to encompass a number of the closely space oxygen ($O_2$) lines from the 50-70 GHz complex of lines. The band was chosen to allow observation on a number of closely space channels within the band, each providing different altitude information.

Temperature profiles are required over all types of land and water surfaces. A relatively small, 10 km or less, resolution element on the surface provides a number of overland observation sites that may be used without severe contamination by the variation of surface emission within a beam. Observations in this band will require supporting observations in the low attenuation frequency bands at 37 and 90 GHz in order to provide estimates of the surface, rain, and cloud effects. For a satellite in a 500 km orbit, a 10 km resolution requires the use of a 0.2 meter antenna, depending on pointing angle. Since the antenna beam traverses a point on the surface in less than 1.0 seconds, the integration time must be less than 1.0 seconds.

**The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is desired. The integration time is determined, not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate from. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and an 84 km vertical scan, a 1 second integration time is required.**

The multifrequency temperature profiling observations need an accuracy of better than 0.3 K to provide temperature estimates within an accuracy of 1 to 2°C. For a Dicke radiometer, with a system noise temperature of 2,300 K, a 0.3 K sensitivity and 1 second integration time, the minimum bandwidth required per measurement channel is 235 MHz. Multiple 235 MHz channels in numerous bands between 50-70 GHz are required to provide temperature sounding approximately every 2 km in altitude.

Temperature profile measurements are needed to support numerical weather forecasting services and observations are required twice per day.

## SHARING ANALYSIS

The 64.0-65.0 GHz frequency band is currently allocated to the Space Research Service on a primary basis in ITU Regions 1, 2, and 3. Since the Earth Exploration Satellite Service (passive) can inherently share with another passive service a primary co-equal allocation is feasible.

# SECTION 13

## FREQUENCY BAND 86 - 92 GHz

## USER REQUIREMENTS

The principal measurements in this band is clouds. The spatial resolution required for cloud observations is 1 km. For a low orbiting satellite in a 500 km circular orbit, a 1 km resolution requires a 1.2 meter antenna. Since the antenna beam traverses a point in less than 0.1 seconds, the integration time must be less than 0.1 second.

Not only are these measurements utilized for clouds, but are an integral part of simultaneous temperature profile measurements. This band is in the atmospheric low attenuation region between the 50-70 GHz oxygen line complex and the isolated oxygen line at 118.75 GHz; hence, surface and cloud effects on temperature profile data can be corrected. Measurements are required at this frequency with sufficient accuracy, 0.2 K, to support the temperature profiling application.

For a Dicke radiometer with a 2300 K system noise temperature, a 1.0 K sensitivity, and a 0.1 second integration time, a minimum bandwidth of 230 MHz is required. In order to image a swath, multiple 26-beam position, limited scanning antennas could be utilized. This would require an integration time of 0.003 seconds and a bandwidth of 6,000 MHz.

Observations are required twice per day to support the temperature profiling applications and once per six hours for cloud measurements.

## SHARING ANALYSIS

The 86-92 GHz band is currently allocated to Radio Astronomy and the Space Research (passive) Services. It is proposed that the band be shared with the Earth Exploration Satellite (passive) Service also. Since the abcve passive services can inherently share with other passive services, frequency sharing is feasible.

Consequently a primary, co-equal allocation is feasible.

# SECTION 14

## FREQUENCY BAND 100 - 102 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide and ozone. Limb scanning measurements are utilized due to certain weak emmissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide and ozone lines. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide or ozone in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 100.5 GHz and the ozone line occurs at 101.7 GHz. Therefore, the overall bandwidth required covers the 99.5 to 102.7 GHz range.

The atmospheric constituents such as nitrous oxide and ozone vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

Portions of the 100-102 GHz band are currently allocated to the Aeronautical Mobile-Satellite, Maritime Mobile-Satellite, Aeronautical Radionavigation-Satellite, Maritime Radionavigation-Satellite and Space Research (passive).

Within the 100-101 GHz Spectral region it has been proposed that the following services be added: Aeronautical Mobile, Maritime Mobile, Aeroanutical Radionavigation, Maritime Radio-navigation, Space Research (passive) and Earth Exploration Satellite (passive).

Since Space Research (passive), which is in the 101-102 GHz spectral region, can inherently share with another passive service, the following analyses addresses the frequency sharing potential with active allocated and proposed services.

This band was not allocated until 1971, when the World Administrative Radio Conference - Space Telecommunications (WARC-ST) made the allocations indicated above. The impermanence of these initial allocations is demonstrated by the sweeping changes which are being considered for U.S. proposals to the GWARC - 1979 as evidenced in the above proposed allocations.

### 14.1 Technical Characteristics

The utility of these frequencies for aeronautical and maritime services is an unknown factor, despite the notation in the forth-coming FCC 3rd Notice of Inquiry (Docket 20271) that: "This frequency band will be used for ship and aircraft communications, position determination and air traffic control".

All major communications and navigation functions in these services are now implemented below 5250 MHz, with some experimentation up to about 15 GHz. The financial viability of budgeting, developing and procuring several new generations of equipment by the year 2000 is seriously questioned.*

Since no equipment, systems, or plans exist in any published literature or government reports indicating the technical characteristics of equipments or systems in this band, it is unwise to attempt to postulate the type of system which might operate in the 100-102 GHz band. A selection of system parameters in this band would be purely arbitrary and the results possibly misleading.

Additionally two other frequency bands below 100 GHz are proposed for allocation to these same services, 45-50 GHz and 66-71 GHz. Considering this, it is not reasonable to expect successive transitions from 5 to 50 to 70 to 100 GHz between now and the year 2000.

---

* "40 & 80 GHz Technology and Assessment and Forecasting," prepared by NSL under contract NAS3-19724 to NASA Lewis Research Center, April 1976.

## 14.2 Conclusions

The probability appears very low, that there will be substantial occupancy of the 100-102 GHz band, by the designated Services before the year 2000. It is proposed that all services presently allocated and proposed for use in the 100-102 GHz band be deleted with the exception of Space Research (passive) and Earth Exploration Satellite (passive) Services. Sharing on a simultaneous operational basis between spaceborne microwave sensors and the Space Research (passive) Service is feasible.

# SECTION 15

# FREQUENCY BAND 105.0 - 126.0 GHz

## USER REQUIREMENTS

The measurements in this band are required to support a number of sensor applications ranging from geosynchronous satellite observations of temperature profiles to limb scanning observations of the stratospheric trace constituents ozone, nitrous oxide, and carbon monoxide.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is desired. The integration time is determined, not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate from. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and an 84 km vertical scan, a 1 second integration time is required. For geostationary observations, the integration, or dwell, time on a resolution element can theoretically vary from 0 to infinity. However, in order to make full earth images within the time between dynamic atmospheric changes, an integration time of one second is considered a practical maximum for each spot.

Measurements in this band require the same sensitivity, 0.2 K, as in all bands above 100 GHz. For a Dicke radiometer with a 4300 K system noise temperature, a 0.2 K sensitivity, and one second integration time, a bandwidth of 1850 MHz is required. The ozone line occurs at 110.8 GHz and carbon monoxide occurs at 115.3 GHz. Temperature sounding requires multiple frequencies centered on and around the oxygen line at 118.75 GHz. Therefore, the overall bandwidth required covers the 105-126 GHz range.

Temperature profiles are required four times per day to provide the data required for automated weather forecasts. Trace constituents observations are required once per week to support seasonal and long-term climate studies.

## SHARING ANALYSIS

The 105-126 GHz band is currently allocated to the Inter-Satellite Service in Regions 1, 2, and 3. Proposed additions include the Fixed and Mobile Service in all three regions. The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed, Mobile and Inter-Satellite Services.

### 15.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 105-126 GHz band can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 15.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 105-126 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors driving the design and implementation of radio links in frequency bands above about 50 GHz are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances tban conventionally employed at frequencies below 15 GHz. It is estimated that the allocation for Fixed and Mobile Services in the 105-126 GHz region will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an sssumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C - G_t - 1/4\pi R^2 - F.M. + A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-91.8 dB(W))

$G_t$ = transmit antenna gain (45 dB(i))

$R$ = hop length (1 km)

F.M. = fade margin (45 dB)

$A_R$ = receive antenna effective area -18 dB($m^2$)

or a required transmitter power of -3.0 dB(W).

### 15.1.2 Sharing Considerations

#### 15.1.2.1 Simultaneous Operations

Normal radiometric measurements in this band will be for sounding of the earth's limb. The maximum level of interference would occur from main beam-to-main beam coupling. The level of this interference is calculated below:

| | | |
|---|---|---|
| Transmitter Power | = | - 3.0 dB(W) |
| Antenna Gain | = | + 45 dB(i) |
| Spreading Loss | = | -139 dB($m^{-2}$) |
| Atmospheric Absorption | = | 70-100 dB |
| Radiometer Antenna Effective Area (main beam) | = | + 2.3 dB($m^2$) |
| | | -164.7 dB(W) |

or 14.7 dB below the radiometer interference level. Considering that as many as 4 interferors could simultaneously be in the main beam horizontal resolution element (4 km) of the radiometer, the interference would still be 8.7 dB below threshold.

*Based on assumed receiver noise figure of 15 dB.

### 15.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the low e.i.r.p.'s envisioned to be employed by digital fixed and mobile systems and the high atmospheric absorption which occurs in this band, sharing on a simultaneous operational basis is feasible.

## 15.2 Inter-Satellite Service

The use of radio communication links between space stations is basically an alternative to employing multiple earth station antenna systems or multiple-hop terrestrial circuits.

Although there has generally been little study as to optimum system configuration (frequency, bandwidth, power, link geometry, etc.), the possible links are:

1) geostationary-to-geostationary satellite links;
2) geostationary-to-low orbit satellite links, and
3) low orbit-to-geostationary links.

Localized areas of interference could be encountered by a spaceborne sensor when: 1) passing through the down-link tracking beam of the geostationary satellite, 2) in close proximity to an up-link transmitting low-orbiting satellite, or 3) pointing (for a limb sounder) directly at the geostationary satellite. Cumulative side lobe interference from multiple inter-satellites is not expected to be an important factor.

The following sections discuss the potential for sharing between Inter-Satellite Service links and passive remote sensors operating in the frequency band. The analyses presented herein are based on worst case conditions in order to address the maximum levels of potential interference.

### 15.2.1 Geostationary-to-Geostationary Link

The only available documentation concerning geostationary-to-geostationary inter-satellite links has been developed by Study Group 4 of the CCIR. This documentation basically discusses communications between spacecraft less than about 30° apart in the geostationary orbit and indicates that the optimum spacing for non-tracking geostationary-to-geostationary links is frequency dependent. Study Group 4 is studying the use of non-tracking communication services below 50 GHz. Therefore, the technical characteristics upon which the underlying sharing analysis is based result from a hypothetical system model which is presented in Annex IV.

The only interference modes, as discussed in Annex IV, that are of concern in this link are for a limb sounder main beam coupling to either the geostationary satellite side lobes or main beam.

15.2.1.1 Technical Characteristics

Several types of geostationary-to-geostationary inter-satellite systems are discussed in Annex IV. The only interference situation occurs for a limb-sounding radiometer operating within the transmit frequency band of a geostationary-to-geostationary inter-satellite system with the following characteristics:

| | | | |
|---|---|---|---|
| Required predetection C/N | = | 10.0 | dB |
| Post detection C/N | = | 20 | dB |
| Receiver noise figure | = | 16 | dB |
| Transmit Bandwidth | = | 2 | GHz |
| Inter-satellite antenna gains | = | 64.4 | dB(i) |
| Transmit power | = | 18.8 | dB(W) |
| Inter-satellite spacing | = | 161.2° | |

The geostationary satellites utilize 4m antennas which are capable of tracking the receiving geostationary spacecraft.

15.2.1.2 Sharing Considerations

15.2.1.2.1 Simultaneous Operations

In order to completely describe potential interference to spaceborne radiometers from geostationary-to-geostationary satellite links, a detailed dynamic sharing model is required. However, an upper bound on the potential for large area

interference situations can be determined under assumed worst case conditions. The assumed interference geometry presented herein includes geostationary satellite spacing of 161° (beam grazing a 500 km orbital altitude) and a spaceborne radiometer orbit inclination and pointing angle (limb sounder) of the antenna such that main beam to main beam antenna coupling could exist. Although it is not expected that this interference situation will ever occur, the following calculation presents an upper bound on potential interference.

| | |
|---|---|
| Transmit e.i.r.p. | = + 83.2 dB(W) |
| Spreading loss | = -163.3 dB |
| Radiometer effective area (main beam & limb sounder) | = + 2.3 |
| | -77.8 dB(W) |

or 72.2 dB(W) above the interference threshold of -150 dB(W).

Due to the very narrow antenna beamwidth employed by both the spaceborne radiometers and geostationary satellites, large isolation from interference may be obtained by small changes in relative orientation of the two satellites. This upper bound calculation indicates that no more than 3% (see Appendix IV) of the radiometer orbital sphere would be lost to data measurements regardless of the radiometer orbital configuration. This upper

bound loss would occur only for inter-satellite systems separated by approximately 160° of the geostationary arc. For systems separated less than 45° of the geostationary arc, no interference could be received by the radiometer even when its antenna is directed at the geostationary satellite. For satellite spacings of between 45 and 161°, much less than 3% of the orbital sphere would be lost to data measurements.

### 15.2.2 Geostationary to Low Orbit Link

A search of national and international data files, as well as published technical documentation has revealed no current utilization or plans for future development of a geostationary to low orbit link in the Inter-Satellite Service in this frequency band. The sharing analysis presented herein is, therefore, based on a theoretical estimate of the technical parameters which would be required to achieve communications on such a link.

#### 15.2.2.1 Technical Characteristics

The technical characteristics of geostationary to low orbit links in the Inter-Satellite Service have been estimated using an assumed design employing spread spectrum techniques. The spread spectrum system design parameters are as follows:

| | |
|---|---|
| Required predetection carrier to noise ratio | = 10 dB |
| Receiver noise figure | = 15 dB |
| Transmission bandwidth | = 2 GHz |
| Geostationary satellite antenna gain | = 60 dB(i) |
| Low orbit satellite antenna gain | = 50 dB(i) |

The geostationary satellite transmitter power required to permit communications over the link can be computed by the following relationship:

$$P_t = N + 10\ \text{dB} - G_t - A_R + L$$

where: $N$ = Receiver noise power

$G_t$ = Transmitting antenna gain

$A_R$ = Receiving antenna effective area

$L$ = Spreading loss.

For the above system parameters the required transmitter power is 29.5 dB(W).

15.2.2.2 Sharing Considerations

15.2.2.2.1 Simultaneous Operations

The worst case interference geometry would be main beam-to-main beam coupling between the geostationary and the radiometer antennas when limb sounders are employed. This interference will occur when the geostationary satellite is tracking a low-orbit satellite that is in the limb of the earth. The interference level in this instance is computed as follows:

ORIGINAL PAGE IS
OF POOR QUALITY

| | |
|---|---|
| Transmitted e.i.r.p. | 89.5 dB(W) |
| Spreading loss | -163.0 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | + 2.4 dB($m^2$) |
| Received interference | -71.1 dB(W) |

or 78.8 dB above the interference threshold of -150 dB(W). For nadir looking radiometers, the interference would be 0.1 dB below the interference level. This interference situation is of such infrequent occurrence, that the loss of radiometer data would be negligible

A limb sounding radiometer will experience interference whenever its main beam is directed at the side lobes of the geostationary satellite as seen from the following calculations:

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB(i) gain) | 29.5 dB(W) |
| Spreading loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | + 2.4 dB($m^2$) |
| | -131.1 dB(W) |

or 18.9 dB above the interference threshold.

Although this level does constitute interference to the radiometer, the length of time that interference would be above threshold is of negligible impact to data measurements. Additionally, the value calculated is conservative in that no consideration is given to potential atmospheric attenuation at the earth's limb.

Another mode of interference couplings, which could be more significant, would occur whenever the radiometer passes through the main beam of a geostationary-to-low-orbit link. In this instance, coupling of the signal would be via the side lobe of the radiometer antenna, and the resulting interference level (identical for both limb and nadir radiometers) is computed as follows:

| | |
|---|---|
| Transmitted e.i.r.p. | 89.5 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Spreading loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area (side lobe) | -76.6 dB($m^2$) |
| Received interference power | -150.1 dB(W) |

or 0.1 dB below the radiometer interference threshold of -150 dB(W).

Consequently, for the interference geometries presented above, no significant interference will be experienced by the radiometer due to the geostationary to low orbit link.

ORIGINAL PAGE IS
OF POOR QUALITY

### 15.2.3 Low Orbit to Geostationary Link

There is currently no available technical documentation concerning development of a low orbit to geostationary links in the Inter-Satellite Service in this frequency band. It may be assumed however, that the link design philosophy would be similar to the geostationary to low orbit link described in paragraph 15.2.2.

#### 15.2.3.1 Technical Characteristics

The technical characteristics of the low orbit to geostationary link have been estimated using an assumed design employing spread spectrum techniques. The design parameters employed are given in paragraph 15.2.2.1. Using the link calculation given therein, the required transmitter power is determined to be 29.5 dB(W).

#### 15.2.3.2 Sharing Considerations

##### 15.2.3.2.1 Simultaneous Operations

The amount of interference received by the radiometer from a transmitter located on a low orbit spacecraft is highly dependent upon the distance between the two spacecraft, which can vary from tens to thousands of kilometers. The spreading loss therefore may fluctuate as much as 60 to 70 dB.

The likelihood of main beam-to-main beam coupling between the two spacecraft is negligibly remote. The radiometer spacecraft would have to be directly above the low orbit communication satellites and in juxtaposition with the geostationary satellites.

The only potential for large areas of interference would be from side lobe to side lobe coupling since the gain at most of the $4\pi$ steradians around the antenna is at 0 dB(i) or lower.

The following calculation determines the separation distance required between two spacecraft in order that side lobe coupling does not cause interference.

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB gain) | 29.5 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Radiometer antenna effective area (side lobe) | -62.6 dB($m^2$) |
| Interference threshold | -( -150 dB(W)) |
| Required spreading loss | 116.9 dB($m^{-2}$) |

or a distance of 197 km.

In order for the spacecraft to pass within this distance, the orbital altitude of the two spacecraft must be within 197 kilometers. If the two spacecraft are to remain within this distance of each other for a significant amount of time, the basic orbital parameters must be nearly identical. It is highly improbable that two spacecraft would be launched into such similar orbits unless it were a matter of design.

### 15.2.4 Conclusions on Sharing with Inter-Satellite Service

Interference would be encountered by passive spaceborne radiometers from operations in the Inter-Satellite Service only when high gain coupling exists between the antennas of the two systems. Although it has not been possible to determine the probability of this occurrence quantitatively (this would involve a complex dynamic computer model) it appears that it would be insignificant and the duration of interference would be of negligible impact to data measurements. An extreme worst case model indicates a maximum data loss of less than 3%. More realistic consideration would indicate that this value is high by possibly several orders of magnitude.

Additionally, even a 3% loss of data in this band would not impair operational radiometric measurements since measurements are being made of large scale atmospherics.

Consequently, sharing on a simultaneous operational basis between these two services is considered feasible and a primary, co-equal allocation is feasible.

# SECTION 16

# FREQUENCY BAND 150-151 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to the weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 150.7 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 150-151 GHz band is currently allocated to the Fixed-Satellite Service in Regions 1, 2 and 3 for Space-to-Earth links. Proposed additions include the Fixed and Mobile Service in all three regions. The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed, Mobile and Fixed-Satellite Services.

### 16.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 150-151 GHz band can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 16.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 150-151 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-2, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors influencing the design and implementation of radio links in the frequency bands above about 50 GHz are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances than conventionally employed at frequencies below 15 GHz. It is anticipated that the allocation for Fixed and Mobile Services in the 150-151 GHz band will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C + FM - G_t + 10\text{Log}\ (4\pi R^2) - A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-91.8 dB(W))

$G_t$ = transmit antenna gain (45 dB(i))

$R$ = hop length (1 km)

FM = fade margin (45 dB)

$A_R$ = receive antenna effective area (-20dB($m^2$))

or a required transmitter power of -0.7 dB(W).

### 16.1.2 Sharing Considerations

#### 16.1.2.1 Simultaneous Operations

Normal radiometer sensing in this band is the limb sounding of the earth's atmosphere. In this mode, the radiometer antenna is directed at or above the earth's horizon.

The worst case interference situation would occur when the main beam of the radiometer is directed at the main beam of the terrestrial station. The level of this interference would be the following:

| | | |
|---|---|---|
| Transmitter Power | = - 0.7 | dB(W) |
| Antenna Gain | = 45 | dB(i) |
| Spreading Loss | = -139 | dB($m^{-2}$) |
| Atmospheric Absorption | =>-100 | dB |
| Radiometer Antenna Effective Area (main beam) | = 15.7 | dB($m^2$) |
| | -210.4 | dB(W) |

or 60 dB below the radiometer interference level.

*Based on assumed receiver noise figure of 15 dB.

ORIGINAL PAGE IS OF POOR QUALITY

## 16.2 Fixed-Satellite Service

A survey of available national and international assignment data files indicates that there are no Fixed-Satellite Service assignments at this time. It is possible, however, that such use will occur at a future date.

It is anticipated that Fixed-Satellite operations in the 150-151 GHz band will make use of multiple feed high gain antennas resulting in coverage of national areas by a number of spot beams. A similar design philosophy would be employed for both up and down links to enable frequency reuse in non-adjacent beam patterns.

### 16.2.1 Technical Characteristics

The technical characteristics for the as yet undeveloped Fixed-Satellite systems in this band are expected to follow the same basic philosophy proposed for Fixed-Satellite systems in lower allocated bands. This philosophy implies the use of relatively high gain antennas at both the spacecraft and earth stations resulting in coverage of a large area by a number of spot beams rather than by use of a single broad beam. In the 150-151 GHz band, space-earth links are subject to considerable fading due to the variability of water vapor in the atmosphere and transient weather phenomena such as heavy clouds, rainfall, etc. A communications link designed to overcome this obstacle would need to employ extremely high gain antennas and/or large transmitting powers. On the spacecraft end of the link, the antenna gain is limited to approximately 65 dB(i) by the pointing accuracy achievable with the spacecraft altitude control system. There is also a limit on transmitter power, since the power needed to operate the spaceborne transmitter is generated on the spacecraft. It is anticipated that the fading associated with operations in this band would be overcome by space diversity techniques. Terrestrial stations would be placed in locations such that the probability that they would be affected by the same weather disturbance would be rather small. The link fade margin needed in a diversity system would be defined by the fades expected due to pointing errors and humidity effects which might be common to both terrestrial sites. A margin of about 12 dB would be sufficient.

The following calculation of required geostationary satellite transmitter power is based on an assumed 10 dB fade margin, a required receiver C/N ratio of 15 dB, and a terrestrial station noise figure of 16 dB. The link calculation assumes a terrestrial antenna elevation of $10^{\circ}$ (worst-case for atmospheric absorption):

$$P_t = N + C/N + FM - G_t + 10 \log(4\pi R^2) + L_a - A_R$$

where: $P_t$ is the required transmitter power

N is the receiver noise power at input

C/N is the required carrier to noise ratio (15 dB) at receiver input

$G_t$ is the spacecraft transmitter antenna gain (65 dBi)

$10 \log(4\pi R^2)$ is the spreading loss (163 dB($m^{-2}$))

$L_a$ is the atmospheric absorption

$A_R$ is the terrestrial receiving antenna effective area (0 dB($m^2$) for gain of 65 dBi)

| | |
|---|---|
| Required C/N ratio | 15 dB |
| Receiver Noise Power (15 dB noise figure in 40 MHz bandwidth) | -113.1 dB(W) |
| Required Received Power | -97.1 dB(W) |
| Receiving Antenna Effective Area | -0 dB($m^2$) |
| Fade Margin | 12 dB |
| Spreading Loss | 163 dB($m^{-2}$) |
| Atmospheric Absorption | +11.5 dB |
| Transmitting Antenna Gain | -{+65 dB(i)} |
| Required Transmitter Power | 23.4 dB(W) |

The resulting transmitter parameters are given as follows:

| | |
|---|---|
| Transmitter Output Power | 23 dB(W) |
| Transmitter Antenna Gain | 65 dB(i) |
| Transmitted e. i. r. p. | 88 dB(W) |

16.2.2 Sharing Considerations

16.2.2.1 Simultaneous Operation

Normal radiometer operations in the 150-151 GHz band will be for atmospheric measurement at the earth's limb. The antenna will have a main beam gain of 49.3 dB(i) and the radiometer susceptible interference level will be -150 dB(W).

Interference may be propagated to the radiometer either on a direct path from the geostationary satellite or by backscatter from the earth.

The interference resulting from direct path coupling into the backlobe of the radiometer antenna is computed as follows:

| | |
|---|---|
| Geostationary Satellite e.i.r.p. = | 88 dB(W) |
| Spreading Loss | -162 dB($m^{-2}$) |
| Radiometer antenna effective area (backlobe) | - 82 dB($m^2$) |
| Interference Level | -156 dB(W) |

or 6 dB below the interference threshold of -150 dB(W).

The interference resulting from direct path coupling into the sidelobe of the radiometer antenna is computed as follows:

| | |
|---|---|
| Geostationary Satellite e.i.r.p. | 88 dB(W) |
| Spreading Loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area | - 79 dB($m^2$) |
| | -154 dB(W) |

or 4 dB below the interference threshold of -150 dB(W).

It is also possible to achieve main lobe to main lobe coupling if the geostationary satellite appears directly beyond the limb of the earth as viewed from the radiometer.

In this circumstance the signal is subjected to atmospheric attenuation equal to twice the surface to space tangential path absorption and the interference level is computed as follows:

| | | |
|---|---|---|
| Geostationary Satellite e.i.r.p. | = | 88 dB(W) |
| Spreading Loss Loss | = | -163 dB($m^{-2}$) |
| Atmospheric Absorption | = | -340 dB |
| Radiometer Antenna Effective Area (main beam) | = | - 15.7 dB |
| | | -430.7 dB(W) |

or 280.7 dB below the interference threshold.

It is possible that up to 50% of the signal from the geostationary satellite could be reflected from the earth's atmopshere. Note that if reflection is from upper layers of the atmosphere there is no absorption of the reflected signal.

The interference for this mode is computed as follows:

| | |
|---|---|
| Geostationary Satellite e.i.r.p. | 88 dB(W) |
| Spreading Loss | -163 dB |
| Power Flux at atmosphere | - 75 dB(W/$m^{-2}$) |
| Reflection cross section (area subtended by radiometer beamwidth) | + 86.7 dB($m^2$) |
| Efficiency factor 50% | - 3 dB(W) |
| Reflected Signal e.i.r.p. | + 8.7 dB(W) |

| | | |
|---|---|---|
| Spreading Loss | -139 | $dB(m^{-2})$ |
| Radiometer Antenna Effective Area (main beam) | - 15.7 | $dB(m^{2})$ |
| Received Interference Power | -146.0 | dB(W) |

or 4 dB above the interference threshold of -150 dB(W).

The loss of coverage area associated with the interference is negligibly small. It is, therefore, feasible to operate sensors in this band on a simultaneous operational basis with the Fixed-Satellite Service.

### 16.2.3 Conclusions on Sharing with the Fixed-Satellite Service

Sharing on a simultaneous operational basis with the Fixed-Satellite Service is feasible. The criteria for sharing is that the e.i.r.p. of the Fixed-Satellite Service spacecraft transmitter does not exceed 88 dB(W).

SECTION 17

FREQUENCY BAND 174.5-176.5

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 175.8 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 174.5-176.5 GHz band is currently allocated to the Inter-Satellite Service in Regions 1, 2, and 3. Proposed additions include the Fixed and Mobile Service in all three regions. The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed, Mobile and Inter-Satellite Services.

### 17.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas

Fixed and Mobile Service development in the 174.5-176.5 GHz band can be expected to make use of digital encoding techniques rather than on the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 17.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 174.5-176.5 GHz region are expected to follow the basic guidelines given in CCIR Reports 387-1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors driving the design and implementation of radio links in frequency bands above about 50 GHz are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distnaces than conventionally employed at frequencies below 15 GHz. It is estimated that the allocation for Fixed and Mobile Services in the 174.5-176.5 GHz region will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C - G_t - 1/4\pi R^2 - F.M. + A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-90.8 dB(W))

$G_t$ = transmit antenna gain (45 dB(i))

$R$ = hop length (1 km)

F.M. = fade margin (45 dB)

$A_R$ = receive antenna effective area (-21.3)

or a required transmitter power of +1.67 dB(W).

### 17.1.2 Sharing Considerations

#### 17.1.2.1 Simultaneous Operations

Normal radiometric sensing in this band will be for sounding of the earth's limb. In this case, the radiometer's antenna is directional at or above the earth's horizon. The worst case interference situation would occur when the antenna is directed at a terrestrial station and in the terrestrial station main beam. This level of interference would be:

| | | |
|---|---|---|
| Transmitter Power | = + 1.6 | dB(W) |
| Antenna Gain | = + 45 | dB(i) |
| Spreading Loss | = -139 | $dB(m^{-2})$ |
| Atmospheric Absorption | = $>$-100 | dB |
| Radiometer Antenna Effective Area (main beam) | = - 1.3 | $dB(m^2)$ |
| | -193.6 | |

or 44 dB below the radiometer interference level.

*Based on assumed receiver noise figure of 16 dB.

### 17.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the low e.i.r.p.'s envisioned to be employed by digital fixed and mobile systems and the high atmospheric absorption which occurs in this band, sharing on a simultaneous operational basis is feasible.

## 17.2 Inter-Satellite Service

The use of radio communication links between space stations is basically an alternative to employing multiple earth station antenna systems or multiple-hop terrestrial circuits.

Although there has generally been little study as to optimum system configuration (frequency, bandwidth, power, link geometry, etc.), the possible links are:

1) geostationary-to-geostationary satellite links;
2) geostationary-to-low orbit satellite links, and
3) low orbit-to-geostationary links.

Localized areas of interference could be encountered by a spaceborne sensor when: 1) passing through the down-link tracking beam of the geostationary satellite, 2) in close proximity to an up link transmitting low-orbiting satellite, or 3) pointing (for a limb sounder) directly at the geostationary satellite. Cumulative side lobe interference from multiple inter-satellites is not expected to be an important factor.

The following sections discuss the potential for sharing between Inter-Satellite Service links and passive remote sensors operating in the frequency band. The analyses presented herein are based on worst case conditions in order to address the maximum levels of potential interference.

17.2.1 Geostationary-to-Geostationary Link

The only available documentation concerning geostationary-to-geostationary inter-satellite links has been developed by Study Group 4 of the CCIR. This documentation basically discusses communications between spacecraft less than about 30° apart in the geostationary orbit and indicates that the optimum spacing for non-tracking geostationary-to-geostationary links is frequency dependent. Study Group 4 is studying the use of non-tracking communication services below 50 GHz. Therefore, the technical characteristics upon which the underlying sharing analysis is based result from a hypothetical system model which is presented in Annex IV.

The only interference modes, as discussed in Annex IV, that are of concern in this link are for a limb sounder main beam coupling to either the geostationary satellite side lobes or main beam.

C-3

17.2.1.1 Technical Characteristics

Several types of geostationary-to-geostationary inter-satellite systems are discussed in Annex IV. The only interference situation occurs for a limb-sounding radiometer operating within the transmit frequency band of a geostationary-to-geostationary inter-satellite system with the following characteristics:

| | | |
|---|---|---|
| Required predetection C/N | = | 10.0 dB |
| Post detection C/N | = | 20 dB |
| Receiver noise figure | = | 17 dB |
| Transmit Bandwidth | = | 2 GHz |
| Inter-satellite antenna gains | = | 64.4 dB(i) |
| Transmit power | = | 23.3 dB(W) |
| Inter-satellite spacing | = | 161.2° |

The geostationary satellites utilize 4m antennas which are capable of tracking the receiving geostationary spacecraft.

17.2.1.2 Sharing Considerations

17.2.1.2.1 Simultaneous Operations

In order to completely describe potential interference to spaceborne radiometers from geostationary-to-geostationary satellite links, a detailed dynamic sharing model is required. However, an upper bound on the potential for large area

interference situations can be determined under assumed worst case conditions. The assumed interference geometry presented herein includes geostationary satellite spacing of 161° (beam grazing a 500 km orbital altitude) and a spaceborne radiometer orbit inclination and pointing angle (limb sounder) of the antenna such that main beam to main beam antenna coupling could exist. Although it is not expected that this interference situation will ever occur, the following calculation presents an upper bound on potential interference.

| | | |
|---|---|---|
| Transmit e.i.r.p. | = | + 87.8 dB(W) |
| Spreading loss | = | -163.3 dB |
| Radiometer effective area (main beam & limb sounder) | = | - 1.3 |
| | | - 76.8 dB(W) |

or 73.2 dB(W) above the interference threshold of -150 dB(W).

Due to the very narrow antenna beamwidth employed by both the spaceborne radiometers and geostationary satellites, large isolation from interference may be obtained by small changes in relative orientation of the two satellites. This upper bound calculation indicates that no more than 3% (see Appendix IV) of the radiometer orbital sphere would be lost to data measurements regardless of the radiometer orbital configuration. This upper

bound loss would occur only for inter-satellite systems separated by approximately 160° of the geostationary arc. For systems separated less than 40° of the geostationary arc, no interference could be received by the radiometer even when its antenna is directed at the geostationary satellite. For satellite spacings of between 40 and 161°, much less than 3% of the orbital sphere would be lost to data measurements.

### 17.2.2 Geostationary to Low Orbit Link

A search of national and international data files, as well as published technical documentation has revealed no current utilization or plans for future development of a geostationary to low orbit link in the Inter-Satellite Service in this frequency band. The sharing analysis presented herein is, therefore, based on a theoretical estimate of the technical parameters which would be required to achieve communications on such a link.

#### 17.2.2.1 Technical Characteristics

The technical characteristics of geostationary to low orbit links in the Inter-Satellite Service have been estimated using an assumed design employing spread spectrum techniques. The spread spectrum system design parameters are as follows:

| | |
|---|---|
| Required predetection carrier to noise ratio | = 10 dB |
| Receiver noise figure | = 15 dB |
| Transmission bandwidth | = 2 GHz |
| Geostationary satellite antenna gain | = 60 dB(i) |
| Low orbit satellite antenna gain | = 50 dB(i) |

The geostationary satellite transmitter power required to permit communications over the link can be computed by the following relationship:

$$P_t = N + 10 \text{ dB} - G_t - A_R + L$$

where: $N$ = Receiver noise power

$G_t$ = Transmitting antenna gain

$A_R$ = Receiving antenna effective area

$L$ = Spreading loss.

For the above system parameters the required transmitter power is 34.2 dB(W).

17.2.2.2 <u>Sharing Considerations</u>

17.2.2.2.1 <u>Simultaneous Operations</u>

The worst case interference geometry would be main beam-to-main beam coupling between the geostationary and the radiometer antennas when limb sounders are employed. This interference will occur when the geostationary satellite is tracking a low-orbit satellite that is in the limb of the earth. The interference level in this instance is computed as follows:

| | |
|---|---|
| Transmitted e.i.r.p. | 94.2 dB(W) |
| Spreading loss | -163.0 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | -1.3 dB($m^2$) |
| Received interference | -70.1 dB(W) |

or 79.9 dB above the interference threshold of -150 dB(W). For nadir looking radiometers, the interference would be 0.9 dB above the interference level. This interference situation is of such infrequent occurrence, that the loss of radiometer data would be negligible.

A limb sounding radiometer will experience interference whenever its main beam is directed at the side lobes of the geostationary satellite as seen from the following calculations:

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB(i) gain) | 34.2 dB(W) |
| Spreading loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area (main beam) | - 1.3 dB($m^2$) |
| | -130.1 dB(W) |

or 19.9 dB above the interference threshold.

Although this level does constitute interference to the radiometer, the length of time that interference would be above threshold is of negligible impact to data measurements. Additionally, the value calculated is conservative in that no consideration is given to potential atmospheric attenuation at the earth's limb.

Another mode of interference couplings, which could be more significant, would occur whenever the radiometer passes through the main beam of a geostationary-to-low-orbit link. In this instance, coupling of the signal would be via the side lobe of the radiometer antenna, and the resulting interference level (identical for both limb and nadir radiometers) is computed as follows:

| | | |
|---|---|---|
| Transmitted e.i.r.p. | 94.2 | dB(W) |
| Spreading loss | -163 | dB($m^{-2}$) |
| Radiometer antenna effective area (side lobe) | - 80.3 | dB($m^2$) |
| Received interference power | -149.1 | dB(W) |

or 0.9 dB above the radiometer interference threshold of -150 dB(W).

Consequently, for the interference geometries presented above, no significant interference will be experienced by the radiometer due to the geostationary to low orbit link.

### 17.2.3 Low Orbit to Geostationary Link

There is currently no available technical documentation concerning development of a low orbit to geostationary links in the Inter-Satellite Service in this frequency band. It may be assumed however, that the link design philosophy would be similar to the geostationary to low orbit link described in paragraph 17.2.2.

#### 17.2.3.1 Technical Characteristics

The technical characteristics of the low orbit to geostationary link have been estimated using an assumed design employing spread spectrum techniques. The design parameters employed are given in paragraph 17.2.2.1. Using the link calculation given therein, the required transmitter power is determined to be 34.2 dB(W).

#### 17.2.3.2 Sharing Considerations

##### 17.2.3.2.1 Simultaneous Operations

The amount of interference received by the radiometer from a transmitter located on a low orbit spacecraft is highly dependent upon the distance between the two spacecraft, which can vary from tens to thousands of kilometers. The spreading loss therefore may fluctuate as much as 60 to 70 dB.

The likelihood of main beam-to-main beam coupling between the two spacecraft is negligibly remote. The radiometer spacecraft would have to be directly above the low orbit communication satellites and in juxtaposition with the geostationary satellites.

The only potential for large areas of interference would be from side lobe to side lobe coupling since the gain at most of the $4\pi$ steradians around the antenna is at 0 dB(i) or lower.

The following calculation determines the separation distance required between two spacecraft in order that side lobe coupling does not cause interference.

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB gain) | 34.2 dB(W) |
| Radiometer antenna effective area (side lobe) | -66.3 dB($m^2$) |
| Interference threshold | -(-150 dB(W)) |
| Required spreading loss | 117.9 dB($m^{-2}$) |

or a distance of 221 km.

In order for the spacecraft to pass within this distance, the orbital altitude of the two spacecraft must be within 221 kilometers. If the two spacecraft are to remain within this distance of each other for a significant amount of time, the basic orbital parameters must be nearly identical. It is highly improbable that two spacecraft would be launched into such similar orbits unless it were a matter of design.

### 17.2.4 Conclusions on Sharing with Inter-Satellite Service

Interference would be encountered by passive spaceborne radiometers from operations in the Inter-Satellite Service only when high gain coupling exists between the antennas of the two systems. Although it has not been possible to determine the probability of this occurrence quantitatively (this would involve a complex dynamic computer model) it appears that it would be insignificant and the duration of interference would be of negligible impact to data measurements. An extreme worst case model indicates a maximum data loss of less than 3%. More realistic consideration would indicate that this value is high by possibly several orders of magnitude.

Additionally, even a 3% loss of data in this band would not impair operational radiometric measurements since measurements are being made of large scale atmospherics.

Consequer sharing on a simultaneous operational basis between these two services is considered feasible and a primary, co-equal allocation is feasible.

# SECTION 18

# FREQUENCY BAND 182-185 GHz

## USER REQUIREMENTS

The primary measurements in this band are of ozone and water vapor. Either limb sounding or geostationary observations may be made.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolutin is desired. The integration time is determined, not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate from. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and an 84 km vertical scan, a 1 second integration time is required. For geostationary observations, the integration, or dwell, time on a resolution element can theoretically vary from 0 to infinity. However, in order to make full earth images within the time between dynamic atmospheric changes, an integration time of one second is considered a practical maximum for individual spot images.

Measurements in this band require the same sensitivity, 0.2 K, as in all bands above 100 GHz. For a Dicke radiometer with a 4300 K system noise temperature, a 0.2 K sensitivity, and one second integration time, a bandwidth of 1850 MHz is required. The water vapor line occurs at 183.3 GHz and the ozone line occurs at 184.75 GHz. Therefore, the overall bandwidth required covers the 182.3-185.7 GHz range.

Water vapor observations are required four times per day to provide the data required for automated weather forecasts. Ozone observations are rquired once per week to support seasonal and long-term climate studies.

## SHARING ANALYSIS

The 182-185 GHz band is currently allocated to Space Research (passive) Service. It is proposed that the band be shared by the Radio Astronomy and the Earth Exploration Satellite (passive) Services. Since the above passive services can inherently share with another passive service, frequency sharing is feasible.

Consequently, primary, co-equal allocations are feasible.

# SECTION 19

## FREQUENCY BAND 200-201.5 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 200.9 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 200-201.5 GHz band is currently an unallocated portion of the radio spectrum Regions 1, 2, and 3. Proposed additions include the Fixed and Mobile Service in all three regions. The following sections analyze the sharing potential between passive spaceborne sensors and the Fixed and Mobile Services.

### 19.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 200-201.5 GHz band can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 19.1.1 Technical Characteristics

The technical characteristics of the yet undeveloped Fixed and Mobile Services in the 200-201.5 GHz band are expected to follow the basic guidelines given in CCIR Reports 387 1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors influencing the design and implementation of radio links in frequency bands above about 50 GHz region are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances than conventionally employed at frequencies below 15 GHz. It is anticipated that the allocation for Fixed and Mobile Services in the 201-201.5 GHz band will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C + FM - G_t + 10 \log(4\pi R^2) - A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-89.8 dB(W))

$G_t$ = transmit antenna gain (45.5 dB(i))

$R$ = hop length (1 km)

FM = fade margin (45 dB)

$A_R$ = receive antenna effective area (-22.5 dB($m^2$)

or a required transmitter power of +3.8 dB(W).

#### 19.1.2 Sharing Considerations

##### 19.1.2.1 Simultaneous Operations

Normal radiometer sensing in this band will be for sounding of the earth's limb. In this mode, the radiometer antenna is directed at or above the earth's horizon.

The worst case interference situation would occur when the main beam of the radiometer antenna is directed at the main beam of the terrestrial station. The level of this interference would be:

| | | |
|---|---|---|
| Transmitter Power | = + 3.8 | dB(W) |
| Antenna Gain | = 45 | dB(i) |
| Spreading Loss | = -139 | dB($m^{-2}$) |
| Atmospheric Absorption | = -100 | dB |
| Radiometer Antenna Effective Area | = - 2.5 | dB($m^2$) |
| | -192.7 | dB(W) |

ORIGINAL PAGE IS OF POOR QUALITY

---

* Based on assumed receiver noise figure of 17 dB.

or 42 dB below the radiometer interference level.

### 19.1.3 Conclusions on Sharing with Fixed and Mobile Services

Sharing on a simultaneous operational basis between the Fixed and Mobile Services and the Earth Exploration Satellite Service (passive) is feasible due to the low required e.i.r.p. of digitally encoded fixed and mobile systems and high attenuation rates in the 200-201.5 GHz band.

Consequently, a primary, co-equal allocation between the space passive services and the Fixed and Mobile Services is feasible. The criteria for sharing with digital fixed and mobile systems is that these systems conform to the specifications of CCIR Reports 387-2, 609, and 610.

SECTION 20

FREQUENCY BAND 225-240 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide, carbon monoxide and oxygen. Limb scanning measurements are utilized due to the weak emissions above 100 GHz and hig atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide carbon nonoxide and oxygen lines. Measurements made at this frequency require a high, 0.2 K sensitivity to detect these molecules in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The lines occurs at 226.1 ($N_2O$), 230.5(CO), 235.7($O_3$), 237.1($O_3$) and 239.1($O_3$). Therefore, the overall bandwidth required covers the 225 to 240 GHz range.

The atmospheric constituents such as the above molecules vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

Portions of the 225-240 GHz band are currently allocated to the Fixed-Satellite Service, the Radio Astronomy Service and Space Research (Passive) Service in Regions 1, 2, and 3. Proposed additions include the Fixed and Mobile Service in all three regions. Since passive services can inherently share, the following sections analyze the sharing potential between passive spaceborne sensors and the Fixed, Mobile and Fixed-Satellite Services.

### 20.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be encountered in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 225-240 GHz band can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 20.1.1 Technical Characteristics

The technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 225-240 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF Carrier by means of phase shift keying.

The prime factors influencing the design and implementation of radio links in frequency bands above about 50 GHz are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances than conventionally employed at frequencies below 15 GHz. It is anticipated that the allocation for Fixed and Mobile Services in the 225-240 GHz region will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C + FM - G_t + 10 \log (4\pi R^2) - A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-88.8 dB(W))

$G_t$ = transmit antenna gain (45 dB(i))

$R$ = hop length (1 km)

$FM$ = fade margin (45 dB)

$A_R$ = receive antenna effective area (-23.7)

or a required transmitter power of +6.13 dB(W).

### 20.1.2 Sharing Considerations

#### 20.1.2.1 Simultaneous Operations

Normal radiometric sensing in this band is sounding of the earth's atmosphere. In this mode, the radiometer antenna is directed at or above the earth's horizon.

The worst case interference situation would occur when the main beam of the radiometer is directed at the main beam of the terrestrial station. The level of this interference would be:

| | | | |
|---|---|---|---|
| Transmitter Power | = | + 6.13 | dB(W) |
| Antenna Gain | = | + 45 | dB(i) |
| Spreading Loss | = | -139 | dB($m^{-2}$) |
| Atmospheric Absorption | = | -100 | dB |
| Radiometer Antenna Effective Area | = | - 3.7 | dB($m^2$) |
| | | -191.5 | dB(W) |

* Based on an assumed receiver noise figure of 18 dB.

or 41.5 dB below the radiometer interference level of -150 dB(W).

### 20.1.3 Conclusions on Sharing with the Fixed and Mobile Services

Sharing on a simultaneous operational basis between the Fixed and Mobile Services and the Earth Exploration Satellite Service (passive) is feasible due to the low required e.i.r.p. of digitally encoded fixed and mobile systems in the 225-240 GHz band.

Consequently, a primary, co-equal allocation between the space passive services and the Fixed and Mobile Services is feasible. The criteria for sharing with digital fixed and mobile systems is that these systems conform to the specifications of CCIR Reports 387-2, 609, and 610.

## 20.2 Fixed-Satellite Service

A survey of available national and international assignment data files indicates that there are no Fixed-Satellite Service assignments at this time. It is possible, however, that such use will occur at a future date.

Very high powers are required to achieve communications in this band. It is anticipated that operations in the 225-240 GHz band would make use of multiple feed high gain antennas resulting in coverage of national areas by a number of spot beams. A similar design philosophy would be employed for both up and down links, to enable frequency reuse in non-adjacent beam patterns. Since the beam patterns would each serve a relatively small area, a large number of earth stations is necessary if the total coverage is to include an extensive service area. At least one earth station would be required for each spot beam.

### 20.2.1 Technical Characteristics

The technical characteristics of the as yet undeveloped Fixed-Satellite Service would be expected to follow the same basic philosophy proposed for the Fixed-Satellite Systems in lower allocated bands. This philosophy implies the use of relatively high gain antennas at both the spacecraft and earth stations resulting in coverage of a large area by a number of spot beams, rather than a single broad beam.

Due to large attenuation of RF signals in the band, large powers are required to establish communications in either direction between earth stations and geostationary spacecraft.

The minimum e. i. r. p. which would allow communications over the link at $10^o$ elevation (worst-case for atmospheric absorption) may be computed from the following formula (a 0 dB fade margin is assumed):

$$P_t = N + C/N + FM - G_t + 10 \log(4\pi R^2) + L_a - A_R$$

where: $P_t$ is the required transmitter power

N is the receiver noise power at input

C/N is the required carrier to noise ratio at the receiver input (15 dB)

$G_t$ is the transmitter antenna gain (65 dBi)

$10 \log(4\pi R^2)$ is the spreading loss (163 dB(m$^{-2}$)

$L_a$ is the atmospheric absorption (33.4 dB)

$A_R$ is the terrestrial receiving antenna effective area (-3.8 dB(m$^2$) for a gain of 65 dBi)

ORIGINAL PAGE IS OF POOR QUALITY

| | |
|---|---|
| Required C/N Ratio | 15 dB |
| Receiver Noise Power at Input (18 dB noise figure in 40 MHz bandwidth) | -110.2 dB(W) |
| Required Received Power | -95.2 dB(W) |
| Receiving Antenna Effective Area | $-\{-3.8\ dB(m^2)\}$ |
| Fade Margin | 0 dB |
| Spreading Loss | $163\ dB(m^{-2})$ |
| Atmospheric Absorption | 33.4 dB |
| Transmitter Antenna Gain | -(+65 dBi) |
| Required Transmitter Power | 40 dB(W) |

or 10 kilowatts for both the geostationary satellite and earth station transmitters.

The spaceborne power requirements for this band are significantly greater than current spacecraft capabilities. Also, a zero dB fade margin would be inadequate.

Thus, on the basis of this analysis, it may be concluded that it is highly unlikely that use will be made of the band 225-240 GHz for the Fixed-Satellite Service in the foreseeable future since the communications need can be satisfied at lower cost through the usage of lower frequency bands allocated for this service, and since require e.i.r.p.'s to meet link budgets in this band are impractically high.

### 20.2.2 Conclusions on Sharing with the Fixed-Satellite Services

It is concluded that due to practical considerations and the availability of spectrum space at lower frequencies that the 225-240 GHz band will not be needed for the Fixed-Satellite Service within the foreseeable future. The allocation for this service should be deleted.

# SECTION 21

# FREQUENCY BAND 250-252 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 251.2 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 250-252 GHz band is currently allocated to the Aeronautical Mobile-Satellite, Maritime Mobile-Satellite, Aeronautical Radionavigation-Satellite, and Maritime Radionavigation-Satellite. It is proposed that this band be used for Aeronautical Mobile, Maritime Mobile, Aeronautical Radionavigation, Maritime Radionavigation, Earth Exploration Satellite (passive) and Space Research (passive).

Since Space Research (passive) can inherently share with another passive service, the following analysis addresses the frequency sharing potential with active allocated and proposed services.

This band was not allocated at all until 1971, when the World Administrative Radio Conference - Space Telecommunications (WARC-ST) made the allocations indicated above. The impermanence of these initial allocations is demonstrated by the sweeping changes which are being considered for U.S. proposals to the GWARC - 1979 as evidenced in the above proposed allocations.

### 21.1 Technical Characteristics

The utility of these frequencies for aeronautical and maritime service is an unknown factor, despite the notation in the forthcoming FCC 3rd Notice of Inquiry (Docket 20271) that: "This frequency band

ORIGINAL PAGE IS
OF POOR QUALITY

will be used for ship and aircraft communications, position determination and air traffic control".

All major communications and navigation functions in these services are now implemented below 5250 MHz, with some experimentation up to about 15 GHz. The financial viability of budgeting, developing and procuring several new generations of equipment by the year 2000 is seriously questioned.*

Since no equipment, systems, or plans exist in any published literature or government reports indicating the technical characteristics of equipments or systems in this band, it is unwise to attempt to postulate the type of system which might operate in the 250-252 GHz band. A selection of system parameters in this band would be purely arbitrary and the results possibly misleading.

There are other bands below 250 GHz that are proposed for allocation to these same services, 45-50 GHz and 66-71 GHz. Considering this, it is not reasonable to expect successive transitions from 5 to 50 to 70 to 250 GHz between now and the year 2000.

* "40 & 80 GHz Technology and Assessment and Forecasting," prepared by NSL under contract NAS3-19724 to NASA Lewis Research Center, April 1976.

## 21.2 Conclusions

The probability appears very low, that there will be substantial occupancy of the 250-252 GHz band, by the designated Services before the year 2000. It is proposed that all services presently allocated and proposed for use in the 250-252 GHz band be deleted with the exception of Space Research (passive) and Earth Exploration Satellite (passive) Services. Sharing on a simultaneous operational basis between spaceborne microwave sensors and the Space Research (passive) Service is feasible.

# SECTION 22

## FREQUENCY BAND 275-277 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 276.3 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 275-277 GHz band is currently unallocated in Regions 1, 2, and 3. Proposed allocations include the Fixed, Mobile and Space Research (Passive) Services in all three regions. Since passive services can inherently share with one another, the following sections analyze the sharing potential between passive spaceborne sensors and the Fixed and Mobile Services.

### 22.1 Fixed and Mobile Services

A survey of available national and international data files indicates that there are no Fixed and Mobile Service assignments at this time. It is possible, however, that such use will occur at a future date. Although the Radio Regulations would allow fixed and mobile systems in all three regions, it is anticipated that installations would be concentrated in highly developed, populated areas, rather than in the more sparsely populated and oceanic areas.

Fixed and Mobile Service development in the 275-277 GHz region can be expected to make use of digital encoding techniques rather than the analog technology used for fixed and mobile systems below 15 GHz. It is expected that the systems installed will consist primarily of fixed link facilities employing relatively high gain antennas.

### 22.1.1 Technical Characteristics

The technical characteristics of the as yet undeveloped Fixed and Mobile Services in the 275-277 GHz band are expected to follow the basic guidelines given in CCIR Reports 387-1, 609 and 610. These guidelines and technical specifications are concerned with broadband, high capacity digital transmissions in which a high speed digital signal is used to modulate the RF carrier by means of phase shift keying.

The prime factors driving the design and implementation of radio links, frequency bands above about 50 GHz are the amounts of absorption due to oxygen and water vapor, and the very large attenuations due to rainfall. These factors limit radio link hops to much smaller distances than conventionally employed at frequencies below 15 GHz. It is anticipated that the allocation for Fixed and Mobile Services in the 275-277 GHz band will be used for intra-city communication networks with hop lengths of 1 km or less.

The following calculation of required fixed or mobile transmitter power is based on an assumed requirement to provide a 45 dB fade margin and a C/I ratio of 14 dB at the fixed or mobile receiver:

$$P_t = C + FM - G_t + 10 \log(4\pi R^2) - A_R$$

where: $P_t$ = required transmitter power

$C$ = received carrier power to provide C/N* of 14 dB (-86.8 dB(W))

$G_t$ = transmit antenna gain (45 dB(i))

R = hop length (1 km)

F M = fade margin (45 dB)

$A_R$ = receive antenna effective area (-25.25 dB($m^2$)

or a required transmitter power of +9.67 dB(W).

## 22.1.2 Sharing Considerations

### 22.1.2.1 Simultaneous Operations

Normal radiometric sensing in this band is sounding of the earth's atmosphere. In this mode, the radiometer antenna is directed at or above the earth's horizon.

The worst case interference situation would occur when the main beam of the radiometer is directed at the main beam of the terrestrial station. The level of this interference would be:

| | | | |
|---|---|---|---|
| Transmitter Power | = | + 9.7 | dB(W) |
| Antenna Gain | = | + 45 | dB(i) |
| Spreading Loss | = | -139 | dB($m^{-2}$) |
| Atmospheric Absorption | = | -100 | dB |
| Radiometer Antenna Effective Area | = | - 5.25 | dB($m^2$) |
| | | -189.5 | dB(W) |

or 39.5 dB below the radiometer interference level.

*Based on an assumed receiver noise figure of 20 dB.

### 22.1.3 Conclusions on Sharing with Fixed and Mobile Services

Due to the low e.i.r.p.'s expected to be employed by fixed and mobile systems in this band and the high atmospheric attenuation, sharing on a simultaneous operational basis, with the Fixed and Mobile Services in the 275-277 GHz band is considered feasible.

Consequently, a primary, co-equal allocation between these services is feasible. The criteria for sharing with the Fixed and Mobile Services is that these systems conform to the general specifications of CCIR Reports 387-2, 609 and 610.

# SECTION 23

# FREQUENCY BAND 300-303 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric nitrous oxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the nitrous oxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect nitrous oxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The nitrous oxide line occurs

at 301.4 GHz.

The atmospheric constituents such as nitrous oxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 300 to 303 GHz band is not currently allocated either internationally or in the U.S.. The U.S. Proposed allocations include government and non-government systems. The non-government allocation is for the Amateur and Amateur Satellite Services. The proposed government allocation is for Earth Exploration Satellite (passive) and Space Research (passive). The analysis herein is concerned with determining the impact of possible amateur transmissions on the passive space services.

### 23.1 Amateur and Amateur Satellite Services

A survey of amateur radio publications concerning activities of amateur radio operations in the 300 to 303 GHz frequency band has revealed no current activity or plans for future transmissions. It may be assumed, however, that should such usage occur, the power levels used and antenna systems employed would be limited to what is achievable with the available technology, provided that maximum levels prescribed by the administrations concerned are not exceeded. The analysis developed herein is based on these assumptions. Since it is not likely that an amateur satellite operating in the band will be launched in the foreseeable future the analysis is confined to terrestrial usage.

### 23.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Amateur and Amateur Satellite services are expected to be defined by the availability of technology and the imposition of the same regulatory philosophy as that in effect for presently allocated amateur bands. Within the foreseeable future, it is not likely that power levels used by amateurs in this band would exceed a few milliwatts or watts at most, and that antenna gains would be confined to not more than 50 dB due to manufacturing tolerance problems and pointing accuracy limitations. For purposes of the analysis however, it is useful to estimate the maximum power that an amateur would be permitted to use, since this figure defines the worst case from the viewpoint of interference. Several administrations allow amateur radio operators a maximum power of 1000 watts or 30 dB(W) i.e., input power to the final stage of the transmitter. The remainder of the administrations have lower power limits. Assuming a 50% efficiency fac+or for the final stage, the technical characteristics of a maximum power amateur station are as follows:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Antenna Gain | 50 dB(i) |
| Transmitted e.i.r.p. | 77 dB(W) |

### 23.1.2 Sharing Considerations

#### 23.1.2.1 Simultaneous Operations

Since radiometric measurements in the band will be made primarily by limb sounders, the maximum interference to the radiometer would occur when the radiometer antenna is directed at the main beam of a Amateur Service transmitter. The level of this interference for a single transmitter would be:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Spreading Loss | -139 dB($m^{-2}$) |
| Atmospheric Loss | -100 dB (as a minimum) |
| Spacecraft Antenna Effective Area | - 6 dB($m^2$) |
| Interference Power which is 18 dB below the interference threshold of -150 dB(W). | -168 dB(W) |

It would be necessary to have about 60 transmitters simultaneously in view for the interference to exceed the interference threshold. The probability of such a situation is negligible.

### 23.1.3 Conclusions on Sharing with Amateur Service

Due to large atmospheric attenuation in the band, sharing on a simultaneous opertional basis is feasible.

Consequently a primary, co-equal allocation is feasible.

## SECTION 24

## FREQUENCY BAND 320-330 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric water vapor. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the water vapor line. Measurements made at this frequency require a high, 0.2 K sensitivity for accurate measurement of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The water vapor line occurs

at 325.1 GHz.

The atmospheric constituents such as water vapor vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 320 to 330 GHz band is not currently allocated either internationaloy or in the U.S.. the U.S. proposed allocations include government and non-government systems. The non-government allocation is for the Amateur Service. The proposed government allocation is for Earth Exploration Satellite (passive), Space Research (passive) and Radioastronomy. Since the passive services can inherently share the frequency band, the analysis herein is confined to determining the impact of possible amateur transmissions on the passive space services.

### 24.1 Amateur Service

A survey of amateur radio publications concerning activities of amateur radio operators in the 320 to 330 GHz frequency band has revealed no current activity or plans for future transmissions. It may be assumed, however, that should such usage occur, the power levels used and antenna systems employed would be limited to what is achievable with the available technology, provided that maximum levels prescribed by the administrators concerned are not exceeded. The analysis developed herein is based on these assumptions.

#### 24.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Amateur Service are expected to be defined by the availability of technology and the imposition of the same regulatory philosophy as that in effect for presently allocated Amateur bands. Within the foreseeable future, it is not likely that power levels used by amateurs in this band would exceed a few milliwatts or watts at most, and that antenna gains would be confined to not more than 50 dB due to manufacturing tolerance problems and pointing accuracy limitations. For purposes of the analysis however, it is useful to estimate the maximum power that an amateur would be permitted to use since this figure defines the worst case from the viewpoint of interference. Several administrations allow amateur radio operators a maximum power of 1000 watts or 30 dB(W) i.e., input power to the final stage of the transmitter. The remainder of the administrations have lower power limits. Assuming a 50% efficiency factor for the final stage, the technical characteristics of a maximum power amateur station are as follows:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Transmitted e.i.r.p. | 77 dB(W) |

24.1.2 Sharing Considerations

24.1.2.1 Simultaneous Operation

Since radiometric measurements in this band will be made primarily by limb sounders, the maximum interference to the radiometer would occur when the radiometer antenna is directed at the main beam of an amateur transmitter antenna. The level of this interference for a single transmitter would be:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Spreading Loss | -139 dB($m^{-2}$) |
| Atmospheric Loss | -100 dB (as a minimum) |
| Spacecraft Antenna Effective Area | - 6.7 dB($m^2$) |
| Interference Power which is 18.7 dB below the interference threshold of -150 dB(W). | -168.7 dB(W) |

It would be necessary to have about 65 transmitters simultaneously in view for the interference to degrade sensor operation. The probability of this situation is negligible.

24.1.3 Conclusions on Sharing with Amateur Service

Due to the large amount of atmospheric absorption in this band, sharing on a simultaneous operational basis is feasible.

Consequently, a primary, co-equal allocation is feasible.

## SECTION 25

## FREQUENCY BAND 340 - 350 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric carbon monoxide. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the carbon nonoxide line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect carbon monoxide in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The carbon nonoxide line occurs

at 345.8 GHz.

The atmospheric constituents such as carbon monoxide vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 340-350 GHz band is not currently allocated to any services. It is proposed that the band be allocated to Earth Exploration Satellite (passive), Space Research (passive) and Radio Astronomy Services. Since the above passive services can inherently share, a primary, co-equal allocation is feasible.

## SECTION 26

## FREQUENCY BAND 360 - 370 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric ozone. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the ozone line. Measurements made at this frequency require a high, 0.2 K sensitivity to detect ozone in the presence of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The ozone line occurs

at 364.4 GHz.

The atmospheric constituents such as ozone vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 360 to 370 GHz band is currently not allocated either internationally or in the U.S.. The U.S. proposed allocations include government and non-government systems. The non-government allocation is for the Amateur Service. The proposed government allocation is for Earth Exploration Satellite (passive), Space Research (passive) and Radioastronomy. Since the passive services can inherently share the frequency band, the analysis herein is confined to determining the impact of possible amateur transmissions on the passive space services.

### 26.1 Amateur Service

A survey of amateur radio publications concerning activities of amateur radio operators in the 320 to 330 GHz frequency band has revealed no current activity or plans for future transmissions. It may be assumed, however, that should such usage occur, the power levels used and antenna systems employed would be limited to what is achievable with the available technology, provided that maximum levels prescribed by the administrators concerned are not exceeded. The analysis developed herein is based on these assumptions.

#### 26.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Amateur Service are expected to be defined by the availability of technology and the imposition of the same regulatory philoscphy as that in effect for presently allocated amateur bands. Within the foreseeable future, it is not likely that power levels used by amateurs in this band would exceed a few milliwatts or watts at most, and that antenna gains would be confined to not more than 50 dB due to manufacturing tolerance problems and pointing accuracy limitations. For purposes of the analysis however, it is useful to estimate the maximum power that an amateur would be permitted to use since this figure defines the worst case from the viewpoint of interference. Several administrations allow amateur radio operators a maximum power of 1000 watts or 30 dB(W) i.e., input power to the final stage of the transmitter. The remainder of the administrations have lower power limits. Assuming a 50% efficiency factor for the final stage, the technical characteristics of a maximum power amateur station are as follows:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Transmitted e.i.r.p. | 77 dB(W) |

26.1.2 Sharing Considerations

26.1.2.1 Simultaneous Operation

Since radiometric measurements in this band will be made primarily by limb sounders, the maximum interference to the radiometer would occur when the radiometer antenna is directed at the main beam of an amateur transmitter antenna. The level of this interference for a single transmitter would be:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Spreading Loss | -139 dB($m^2$) |
| Atmospheric Loss | -100 dB (as a minimum) |
| Spacecraft Antenna Effective Area | - 7.7 dB($m^2$) |
| Interference Power which is 19.7 dB below the interference threshold of -150 dB(W). | -169.7 dB(W) |

It would be necessary to have about 93 transmitters simultaneously in view for the interference to degrade sensor operation. The probability of such a situation is negligible.

### 26.1.3 Conclusions on Sharing with Amateur Service

Due to the large amount of atmospheric attenuation in the band, sharing on a simultaneous operational basis is feasible.

Consequently, a primary, co-equal allocation is feasible.

## SECTION 27

## FREQUENCY BAND 375 - 385 GHz

## USER REQUIREMENTS

The primary measurements in this band are of stratospheric water vapor. Limb scanning measurements are utilized due to certain weak emissions above 100 GHz and high atmospheric loss encountered by nadir devices. Limb scanning instruments utilize long, nearly horizontal, paths through the stratosphere. Observations are required at and near the water vapor line. Measurements made at this frequency require a high, 0.2 K sensitivity for accurate measurement of water vapor.

The resolution involved in limb scanning is the altitude resolution obtained and is provided by the antenna beamwidth. A 1-2 km vertical resolution is required. The integration time is determined not only by the orbit altitude and antenna resolution, but by the along-track region from which the bulk of the emissions emminate. Typically, this along-track dimension is on the order of 300 km. In order not to take measurements from the same volume on the next scan, the spacecraft should move at least 300 km before starting a new scan. For a 500 km circular orbit, a 2 km vertical resolution, and a 84 km vertical scan, a 1 second integration time is required.

For a Dicke receiver with a 4300 K system temperature a 0.2 K sensitivity and one second integration time, the minimum bandwidth required is 1850 MHz. The water vapor line occurs

at 380.2 GHz.

The atmospheric constituents such as water vapor vary slowly in time, and one observation per week is adequate to obtain the required data on seasonal variations.

## SHARING ANALYSIS

The 375 to 385 GHz band is currently not allocated either internationally or in the U.S. The U.S. proposed allocations envision sharing between government and non-government use. The non-government allocation is for the Amateur Service. The proposed government allocation is for Earth Exploration Satellite (Passive), Space Research (Passive) and Radioastronomy. Since the passive services can inherently share the frequency band, the analysis herein is confined to determining the impact of possible amateur transmissions on the passive space services.

### 27.1 Amateur Service

A survey of amateur radio publications concerning activities of amateur radio operators in the 375 to 385 GHz frequency band has revealed no current activity or plans for future transmissions. It may be assumed, however, that should such usage occur, the power levels used and antenna systems employed would be limited to what is achievable with the available technology, provided that maximum levels prescribed by the administrators concerned are not exceeded. The analysis developed herein is based on these assumptions.

#### 27.1.1 Technical Characteristics

Technical characteristics of the as yet undeveloped Amateur systems are expected to be defined by the availability of technology and the imposition of the same regulatory philosophy as that in effect for presently allocated Amateur bands. Within the foreseeable future, it is not likely that power levels used by amateurs in this band would exceed a few milliwatts or watts at most, and that antenna gains would be confined to not more than 50 dB due to manufacturing tolerance problems and pointing accuracy limitations. For purposes of the analysis however, it is useful to estimate the maximum power that an amateur would be permitted to use since this figure defines the worst case from the viewpoint of interference. Several administrations allow amateur radio operators a maximum power of 1000 watts or 30 dB(W) i.e., input power to the final stage of the transmitter. The remainder of the administrations have lower power limits. Assuming a 50% efficiency factor for the final stage, the technical characteristics of a maximum power amateur station are as follows:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Transmitted e.i.r.p. | 77 dB(W) |

27.1.2 Sharing Considerations

27.1.2.1 Simultaneous Operation

Since radiometric measurements in this band will be made primarily by limb sounders, the maximum interference to the radiometer would occur when the radiometer antenna is directed at the main beam of an amateur transmitter antenna. The level of this interference for a single transmitter would be:

| | |
|---|---|
| Transmitter Power | 27 dB(W) |
| Transmitter Antenna Gain | 50 dB(i) |
| Spreading Loss | -139 dB($m^2$) |
| Atmospheric Loss | -100 dB (as a minimum) |
| Spacecraft Antenna Effective Area | - 8 dB($m^2$) |
| Interference Power which is 70 dB below the interference threshold of -150 dB(W). | -170 dB(W) |

It would be necessary to have about 100 transmitters simultaneously in view for the interference to degrade sensor operation. The probability of such a situation is negligible.

### 27.1.3 Conclusions on Sharing with Amateur Service

Due to the large amount of atmospheric attenuation in the band, sharing on a simultaneous operational basis is feasible.

Consequently, a primary, co-equal allocation is feasible.

# APPENDICES I - V

# APPENDIX I

## GAIN-RANGE QUOTIENT ANALYSIS

Gain-range quotient calculations permit the generation of a map that pictorially describes the loss of coverage area that results from interference to a passive sensor.

The gain-range model is based upon a parametric analysis of potential interference situations. The harmful interference power, $\Delta P_H$, seen at the passive radiometric input is given by:

$$\Delta P_H = 0.2\ k\Delta T\ B\ (W) \tag{1}$$

where $k$ = Boltzmann's constant (Watts/K/Hz)

$\Delta T_{rms}$ = Receiver minimum discernible temperature differential (K)

$B$ = Receiver bandwidth (Hz)

In relation to the interfering source,

$$\Delta P_H = \frac{P_t G_t G_R}{4\pi R^2} \left(\frac{\lambda^2}{4\pi}\right) \tag{2}$$

where: $G_t$ = Gain of transmitting antenna

$P_t$ = Power of transmitting source (Watts)

$G_R$ = Gain of receiver antenna

$\lambda$ = Wavelength (meters)

$R$ = Range (meters)

Rearranging Equation (2)

$$\frac{\Delta P_H (4\pi)^2}{P_t \lambda^2} = \frac{G_t G_R}{R^2} \tag{3}$$

In this analysis, the right hand side of Equation 3 is termed the "gain-range quotient" and may be calculated independently of $\Delta P_H$, $P_t$ and $\lambda$ as follows. The area of the spacecraft's orbital sphere visible to a given terrestrial station is divided into small incremental regions called "bins", (e.g. 2° x 2° latitude-longitude regions, see Figure I-1). For each of these regions, the gain of the spacecraft antenna in the direction of the terrestrial station, the gain of the terrestrial station in the direction of the spacecraft, and a range between the spacecraft and the terrestrial station may be calculated. With these values determined, the gain-range quotient is known. Under the assumption that the bins are small and the functions are slowly varying, the gain-range quotient for each bin is assumed to apply over that entire bin area.

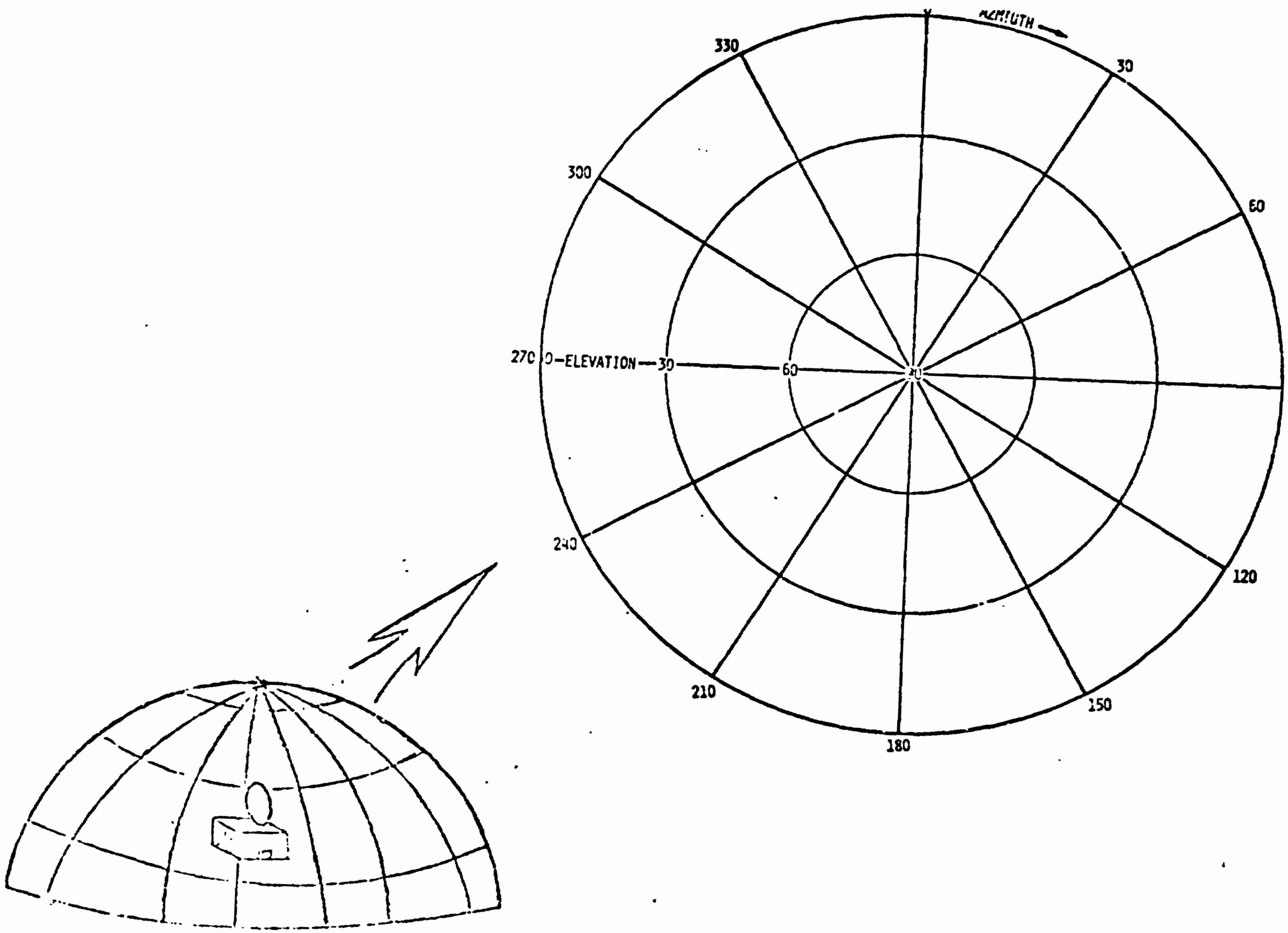
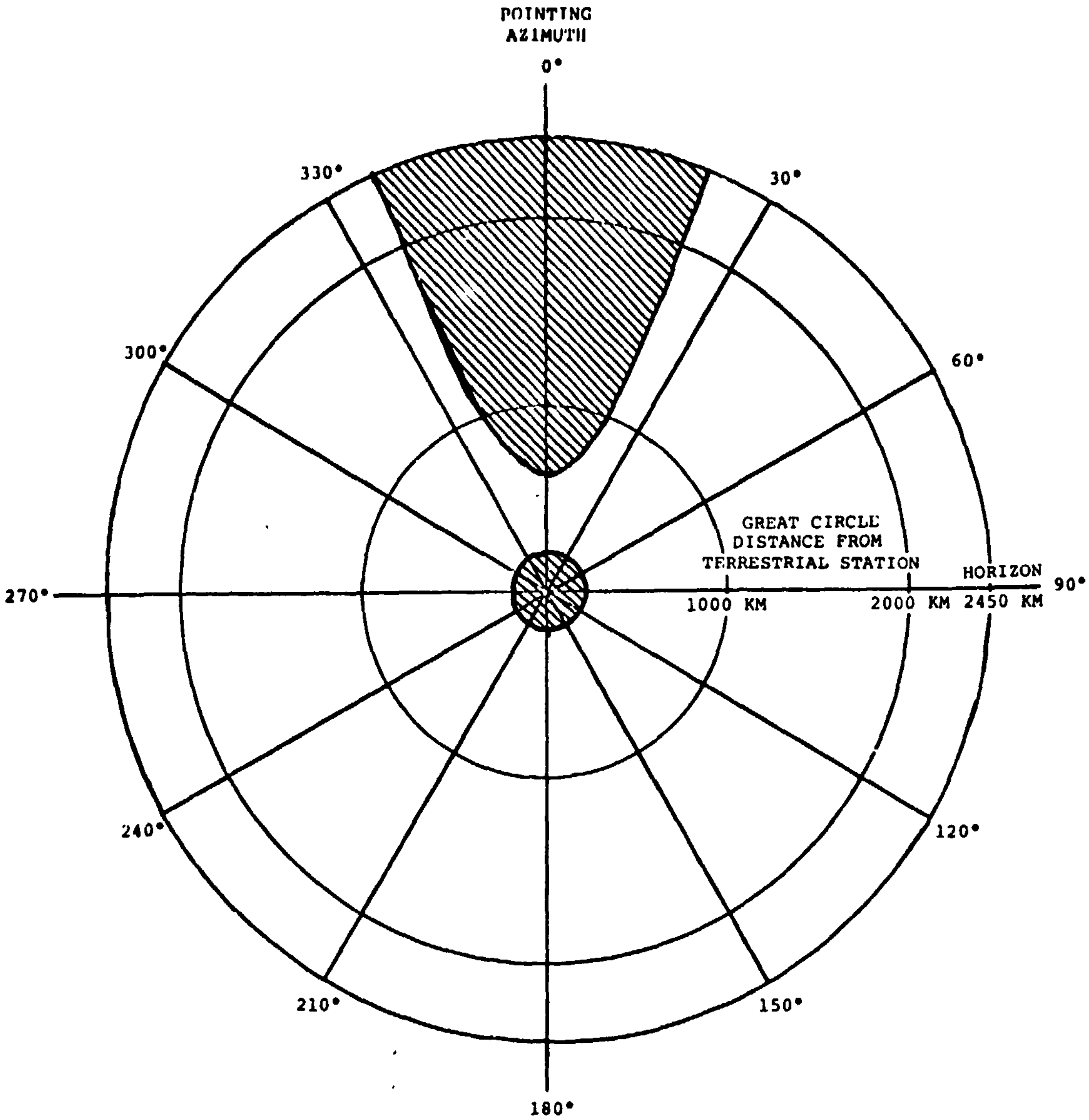



Figure I-1  AZ-EL Bin Structure Surrounding Terrestrial Station

If this process is repeated for each bin, a map of gain-range quotients vs. spacecraft location is achieved. It should be noted that the gain-range quotient map is, at this point, independent of frequency, transmit power and harmful interference power. It is dependent only on the orbital altitude and specific antenna patterns used for the spacecraft and terrestrial station. If the antenna patterns used closely represent the terrestrial and space systems, then all that need be done to determine approximate interference regions on the map is to calculate the minimum tolerable gain-range quotient using $\Delta P_H$, $P_t$, $\lambda$, etc. from Equation 3.

The utility of this approach lies on the map-like presentation of potential interference regions. Passive spaceborne sensors, are generally used to produce radiance maps of the earth's surface or atmosphere. The interference maps indicate regions of the earth's surface which are unavailable for sensor operation. Figure I-2 presents an example map. The gain-range program differs from the Random Interference Analysis Program (Appendix II) in that it is intended to generate the areas of geographical coverage lost to a spaceborne radiometer when in view of a single terrestrial station.




Note: Shaded areas indicate region where interference and therefore, loss of coverage occurs. Terrestrial station is located in center.

Figure I-2 Sample Loss of Coverage Area Map

ORIGINAL PAGE IS
OF POOR QUALITY

# APPENDIX II

## RANDOM INTERFERENCE ANALYSIS PROGRAM

The Random Interference Analysis Program was developed to determine the cumulative effects of numerous terrestrial stations simultaneously visible to a spaceborne radiometer.

This technique utilizes a random number generator to place terrestrial stations within the field of view of the radiometer. The terrestrial stations are located at random great circle distances from the spacecraft subsatellite point, and assigned a random pointing direction. Based upon the terrestrial transmit power, gain patterns of both the terrestrial and radiometer antennas, and range to the spacecraft, the interference power at the input to the radiometer is calculated. If the calculated level of interference is above the radiometer threshold, the program notes that one station caused interference. If the level is not above threshold, a second station is randomly placed in the region visible to the radiometer, and its interference power is calculated and added to that of the first station. The result is again compared to the radiometer threshold. This process is continued until the radiometer interference threshold is exceeded.

In order for this process to generate meaningful results, it is necessary to repeat the above procedure a large number of times to obtain a statistically significant number of samples.

Table II-1 presents an example output of the program, at the point where the cumulative interference exceeds the radiometer threshold. Column two indicates the number of times that the interference threshold was reached or exceeded for the number of stations in Column 1. For example, row 1 of Table II-1 indicates that interference from a single station, placed and pointed randomly, exceeded the radiometer threshold 132 times. This corresponds to a 13.2% (based on 1000 total samples) probability. In 319 samples, interference from two stations exceeded the interference threshold corresponding to a 31.9% probability. For these 1000 data samples, the radiometer could tolerate no more than 10 stations and radiometer data was lost whenever 10 or more were simultaneously in view.

TABLE II-1

Example Output of
Random Interference Analysis Program

| No. Stations | Number of Times Interference Experienced | Probability of Interference (%) |
|---|---|---|
| 1 | 132 | 13.20 |
| 2 | 319 | 31.90 |
| 3 | 532 | 53.20 |
| 4 | 718 | 71.80 |
| 5 | 859 | 85.90 |
| 6 | 925 | 92.50 |
| 7 | 972 | 97.20 |
| 8 | 991 | 99.10 |
| 9 | 998 | 99.80 |
| 10 | 1000 | 100.00 |

# APPENDIX III

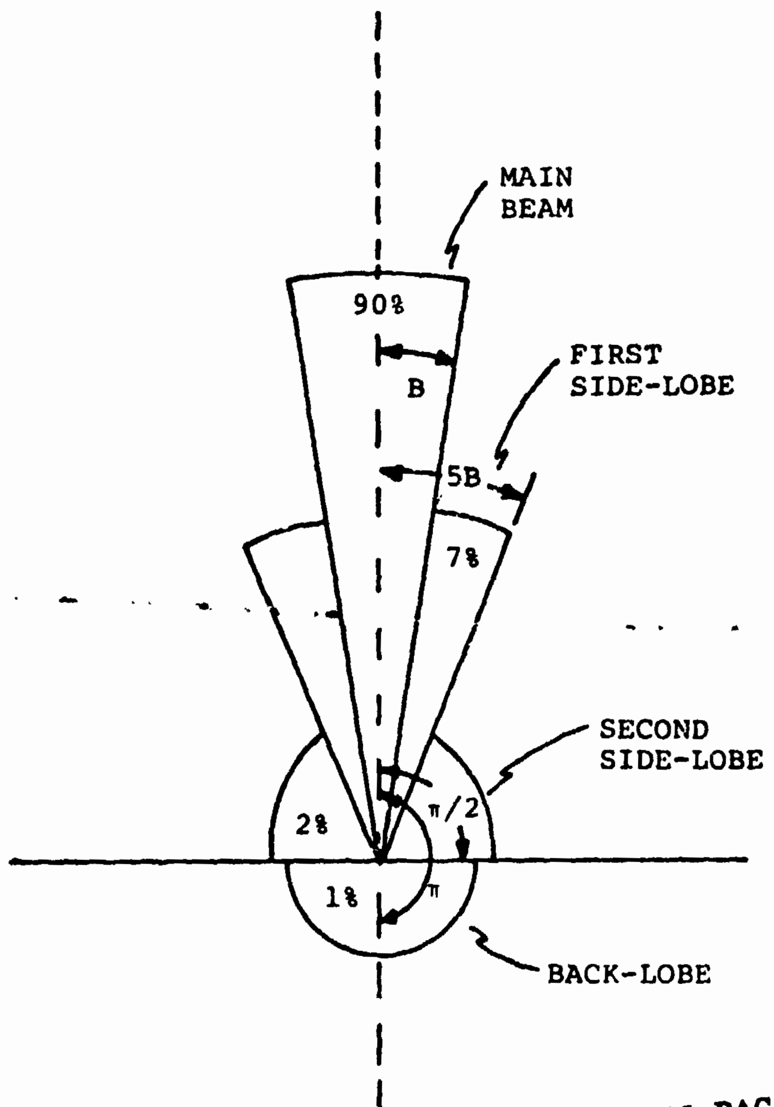
## ANTENNA PATTERNS

Due to the nature of the multifrequency analyses performed, it has not been possible to obtain actual measured antenna patterns. Therefore, it has been necessary to utilize several mathematical envelope patterns approximating actual antenna patterns.

### 1. Passive Radiometer Antenna Patterns

An under-illuminated antenna envelope pattern was developed to model narrow "pencil" beams, used by radiometers for obtaining high resolution maps of the earth's surface. A 90% beam efficiency (90% of the energy entering the antenna enters within the -20 dB points) is postulated. The first sidelobe level is assumed to have a fixed level extending to 5 times the 3 dB half angle, and receives 7% of the energy. The secondary sidelobe region extends to an off-axis angle of 90°, and receives 2% of the energy. These sidelobe gain levels are a reasonable approximation of an under-illuminated pencil beam antenna. The development of this pattern is based on conservation of energy principles (i.e., the gain summed over the entire antenna must equal that of an isotrope.) Figure III-1 shows the envelope pattern of the simulated antenna.

PRECEDING PAGE BLANK NOT FILMED




ORIGINAL PAGE IS
OF POOR QUALITY

Figure III-1. Under-illuminated Antenna Radiation Pattern.

## 2. Terrestrial and Earth Station Antenna Patterns

The parabolic terrestrial and earth station antenna patterns used in the sharing analyses were based on CCIR recommended patterns. Specifically, CCIR 95th percentile peak side-lobe gain patterns given by:

$$G(\theta) = 32-25 \log(\theta) \text{ for } D/\lambda>100$$

$$G(\theta) = 38-25 \log(\theta) \text{ for } D/\lambda<100$$

where: $G(\theta)$ = the side-lobe antenna gain referenced to an isotropic (dB(i))

$\theta$ = off-axis angle as seen at the antenna (deg.)

$D$ = antenna dimeter (m), and

$\lambda$ = wavelength (m)

## 3. Fixed-, Mobile- and Broadcasting-Satellite Antenna Patterns

The reference radiation antenna patterns recommended for use for broadcasting-satellite antennas is contained in CCIR Draft Report AF/10-11 Geneva, 1976 and is as follows:

$$G_D = -12\left(\frac{\phi}{\phi_o}\right)^2 \text{ for } 0 \leq \phi \leq 1.44\phi_o$$

$$G_D = -25 \text{ for } 1.44\phi_o < \phi \leq 3.16$$

$$G_D = -[12.5+25 \log_{10}\left(\frac{\phi}{\phi_o}\right)] \text{ for } 3.16\ \phi_c < \phi$$

ORIGINAL PAGE IS OF POOR QUALITY

where: $\phi_o$ = 3 db beamwidth (deg.)

$\phi$ = off-axis angle (deg.)

$G_D$ = gain discrimination

This pattern very closely approximates that pattern currently accepted for the Fixed-Satellite Service and therefore it has been used for all the geostationary spacecraft sharing analyses.

APPENDIX IV

INTER-SATELLITE SYSTEM DEVELOPMENTS

## 1. INTRODUCTION

This annex describes the generalized models used to determine transmission parameters for satellite links in the Inter-Satellite Service and presents sample interference analyses for the 54.9 to 55.1 GHz band. Two types of system models are considered, a non-tracking communication system utilizing antennas which are fixed to the body (or despun portion) of the spacecraft, and a system utilizing tracking-antennas, i.e., antennas which may be pointed independently of the spacecraft attitude perturbations. The principal difference between these two models is that the antenna beamwidth of the non-tracking system must be large enough to accommodate the relative angular motions of both the transmitting and receiving spacecraft.

## 2. GEOSTATIONARY-TO-GEOSTATIONARY SATELLITE MODELS

### 2.1 N -Tracking Inter-Satellite Systems

One of the models used to describe the non-tracking geostationary-to-geostationary inter-satellite systems is based on information contained in CCIR Document 451-1 (rev 76). This document gives values for expected satellite relative station-keeping errors of future inter-satellite systems and are as follows:

| | |
|---|---|
| Altitude variation | $\pm$ 12 km |
| North/South | $\pm$ 8 km |
| East/West | $\pm$ 73 km |

These values are relative in that it is expected that the phase of the cyclic orbital perturbation of the two inter-satellites would be as closely matched as possible, in order to reduce the apparent angular motion of one spacecraft as seen from the other. Figure 1 illustrates the effect of the relative station-keeping errors in terms of apparent angular displacements as a function of the geocentric orbital separation of the two spacecraft.

Figure 1 indicates that for relatively small angular separations, (e.g., up to about 30°) the altitude variation causes the largest uncertainty in the location of the spacecraft, while at large separation angles the dominant factor is the east-west station-keeping capability.

Since, for the non-tracking system, the antenna beamwidths must be wide enough to encompass the relative satellite station-keeping errors, in addition to compensating for the transmitting satellite' attitude errors, Figure 1 implies that narrowbeam high-gain antennas can only be utilized when the two satellites are sufficiently separated in orbit.

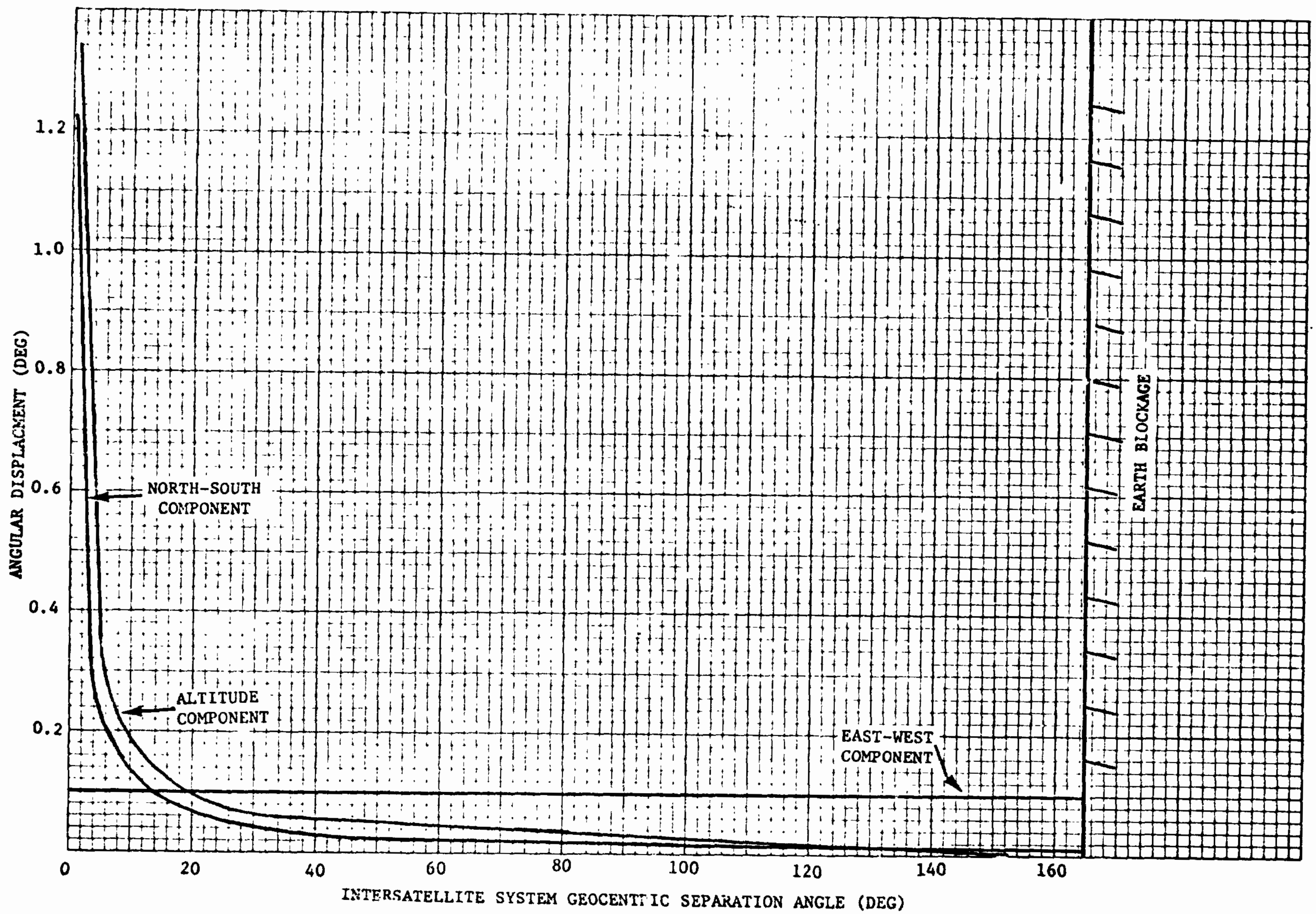



FIGURE 1. RELATIVE ANGULAR ERROR DUE TO STATIONKEEPING UNCERTAINTIES

Equation 1 gives the power required by the transmitting satellite as a function of the satellite separations, antenna diameters, frequency and other link and physical parameters of the inter-satellite system.

$$P = \frac{(C/N)\ KT(f)b}{G_R G_T} \left(\frac{\lambda}{4\pi R}\right)^{-2} \qquad (1)$$

where:

$G$ = main beam gain = $\left(\frac{\pi D}{\lambda}\right)^2 \eta$

$f$ = frequency (GHz)

$\lambda$ = wave length (m)

$T$ = receiver temperatue = $9000\sqrt{f/55}$

$p$ = power (Watts)

$D$ = antenna diameter (m)

$R$ = range (m) = $R_g\sqrt{2(1-\text{Cos}\ \phi)}$

$R_g$ = geostationary distance to center of Earth

$\phi$ = geocentric separation angle (deg)

$K$ = $1.38 \times 10^{-23}$ dBW/K/Hz Boltzmann's constant

$b$ = bandwidth (Hz)

$C/N$ = carrier-to-noise ratio

Three of the terms shown in Equation (1) require elucidation. The receiver noise temperature variation with frequency is based on a noise figure of 15 dB at 55 GHz. The bandwidth and carrier-to-noise ratio chosen for the non-tracking model are 100 MHz and 30 dB respectively. These values are typical of communication links that may be used by Intelsat type traffic (i.e., generally multiplexed voice-traffic). Since the service requirements for commercial traffic are generally quite high, it is felt that these requirements represent a practical worst case for development of the transmit power for non-tracking systems, and therefore for interference to a spaceborne radiometer.

It should be noted that one of the principal reasons put forth by the fixed-satellite community for utilizing inter-satellite links is the reduction of the time delay which would occur over a fixed satellite two-hop link. This time delay could be considerably reduced by utilizing close inter-satellite relays between spacecraft. However, two inter-satellite spacecraft having an orbital separation of 30° would have 66% of the time delay of full two-hop system. For this reason, it would be expected that the commercial voice traffic would be restricted to inter-satellite communications between relatively closely space spacecraft.

## 2.2 Tracking Inter-Satellite Systems

It is possible that inter-satellite systems which do not utilize "Intelsat-type" traffic will come into existance. For example, earth resource images, or other types of wide band digital data, may be relayed between geostationary spacecraft.

Such systems would require greater information bandwidths than the previously discussed systems but would carry digital traffic which is not impacted by propagation delays. For the purposes of this analysis a digital signal, with a 200 MHz information bandwidth, is assumed.

Further it is assumed that a post-detection S/N ratio of 20 dB would be sufficient and that this would be accomplished via a first detection C/N of 10 dB and a modulation technique (spread spectrum) yielding 10 dB processing gain. This implies that the original 200 MHz information bandwidtn would be spread on the order of 10:1 and therefore the transmitted bandwidth would be approximately 2 GHz.

## 2.3 Transmitter Power Requirements

Figure 2 presents the inter-satellite transmit power requirement for the tracking-antenna system model and for two different non-tracking system models as a function of spacecraft orbital separation. The non-tracking system models are developed by utilizing an antenna beamwidth large enough to encompass the maximum angular area of uncertainty (shown in Figure 1) in addition to a 0.1° attitude uncertainty. Figure 2 presents the required power for non-tracking systems with antenna diameter upper limits of 1.2 and 2 meters. The tracking system is assumed to utilize a 0.1° beamwidth antenna.

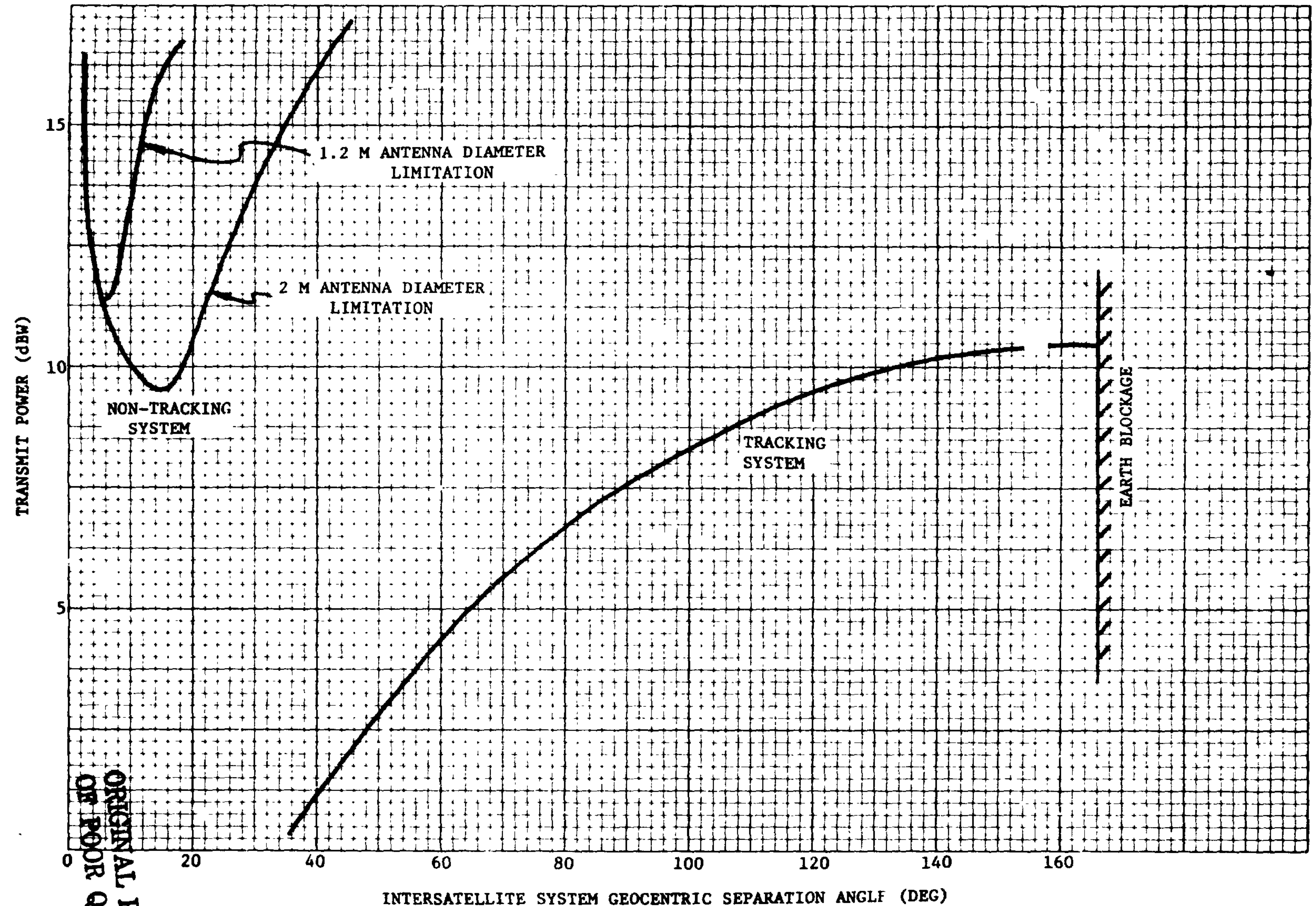





FIGURE 2. 54 GHz INTERSATELLITE SYSTEM REQUIRED TRANSMIT POWER

These models lead to parameters which may be reasonable for inter-satellite systems in the 50 to 60 GHz portion of the spectrum; that is, maximum antenna sizes of either 2 meters for the non-tracking system (i.e., compatible with large launch vehicles) or 4 meters for the tracking systems (compatible with shuttle-type payloads).

Figure 2 indicates that at 54 GHz the non-tracking system has an optimum (i.e., minimum power) angular separation. This occurs because the increased achievable gain as the spacecraft are separated, more than compensates for the increasing range between the spacecraft. The minimum power requirement is reached at the point where the antenna size reaches the indicated limit even though the relative angular motions of the spacecraft are still decreasing. From this point on, the antenna gain remains constant and the transmit power must be increased to compensate for the increased spreading loss as the spacecraft separations are increased. At geocentric spearation angles beyond about 30° the transmitting power requirements for non-tracking systems rapidly become prohibitive.

Since worst case interference to a low orbiting radiometer would occur from geostationary spacecraft communications across large orbital arcs (and therefore grazing the earth's limb), the technical parameters of tracking geostationary-to-geostationary inter-satellite systems are utilized in all sharing analyses to which this Appendix applies.

## 2.4 Interference Analysis Procedure

In order to assess potential interference from geostationary-to-geostationary satellite links it is necessary to make certain assumptions as to the technical characteristics of the link. A method by which an upper bound on the potential interference may be placed is described below.

Since the level of interference received by either a limb sounder or a nadir-looking radiometer is a function of the orbital separation of the geostationary spacecraft (which determines the required transmit power and off-axis antenna gains), the following figures present the interference level as a function of orbital separation angle of the geostationary spacecraft.

Figure 3 illustrates the worst case interference level received by a nadir-looking radiometer when two geostationary satellites are communicating with one another. Additionally, the interference threshold for the radiometer is shown by the dashed line. As illustrated in the Figure, no interference will occur. Interference threshold is approached only when the main beam of the transmitting inter-satellite spacecraft approaches the earth - even in this case, the interference is 10.7 dB below the threshold of the radiometer.

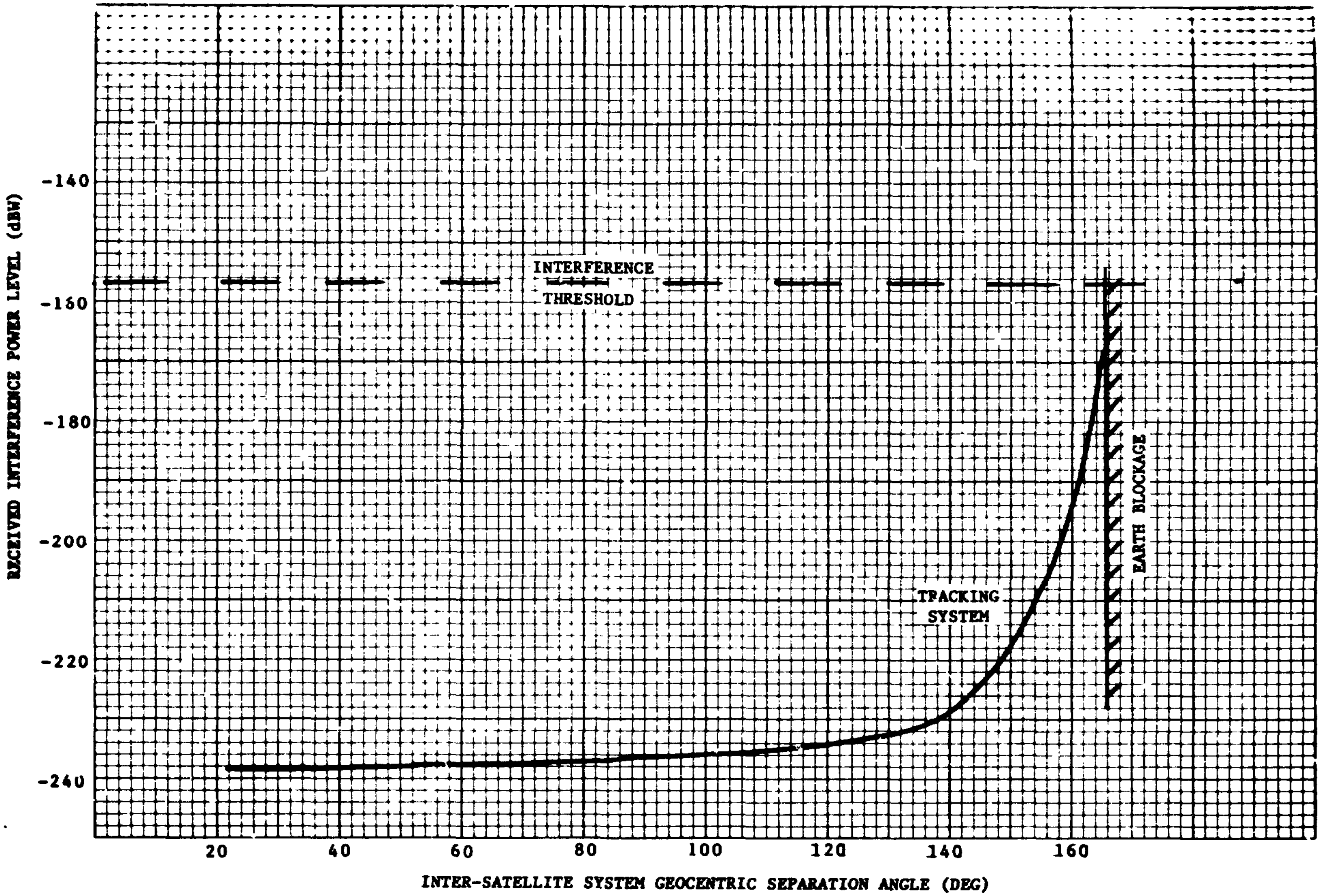



FIGURE 3. WORST CASE INTERFERENCE POWER RECEIVED BY NADIR-LOOKING RADIOMETER AT 54.9-55.1 GHz

It should be noted that there has been no allowance made for atmospheric loss in the interference path in this portion of this analysis. These losses, however, will provide additional margin against interference.

The conclusion, then, is that nadir-looking radiometers should experience no interference from geostationary-to-geostationary communication links in the 54.9-55.1 GHz inter-satellite band.

Figure 4 illustrates the power received by a limb-sounding radiometer under worst case* conditions as a function of the separation of the inter-satellite spacecraft. The interference level for the radiometer is indicated by a dashed line in the figure.

The peak interference level presented in Figure 4 represents a main-beam to main-beam coupling situation between the geostationary spacecraft and the limb sounder. Although this situation in reality would not occur for anticipated Earth Exploration Satellite orbits, it is presented only to set an upper bound on potential interference. In this example, a maximum interference level of 68 dB above threshold cou[illegible] encountered.

In order to bound the area of the orbital sphere i[illegible] interference above threshold would occur, it is necessa[illegible] determine the relative position of the radiometer spacecraft to provide antenna discriminations equal to 68 dB.

*This worst case condition is defined as the main beam of the radiometer pointing directly at the transmitting inter-satellite system.

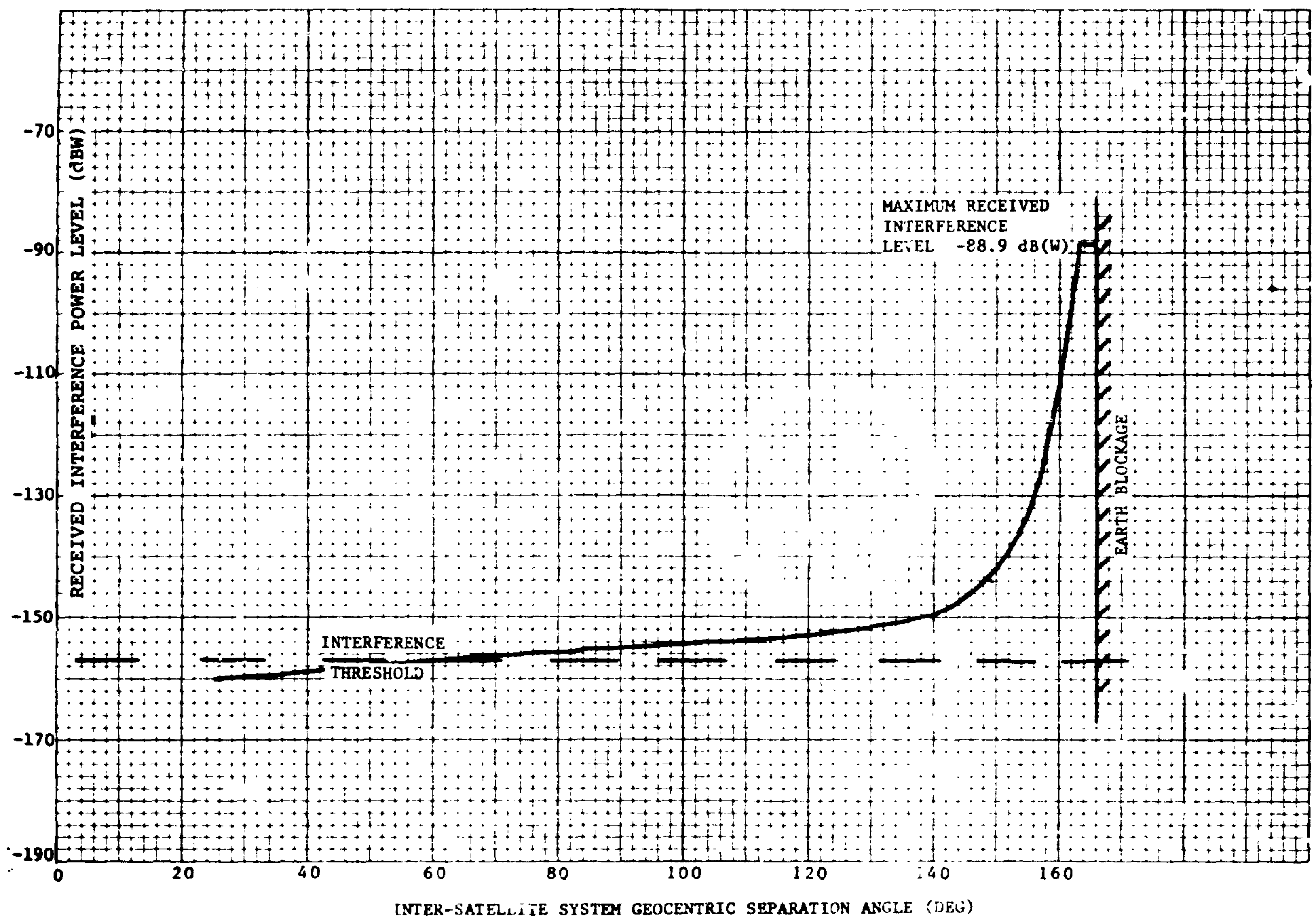



FIGURE 4. WORST CASE INTERFERENCE POWER RECEIVED BY LIMB-SOUNDING RADIOMETER AT AT 54.9-55.1 GHz

ORIGINAL PAGE IS OF POOR QUALITY

Figure 5 presents minimum combined antenna discrimination as a function of east-west and north-south relative motion of the radiometer away from the point* of maximum interference. It can be seen from this figure that an east-west motion of the radiometer of only 0.5° yields the required discrimination, while a north-south motion of 12° is required. These angles then, respectively, represent the semi-minor and semi major axis of a pseudo-elliptical region lying on the equator with the long axis (12° x 2 = 24° in length) oriented in the north-south direction. This region represents about 3% of the total 500 km orbital sphere.

This 3% loss represents the worst case and for all other geometrical configurations the interference area would significantly be diminished. Additionally, for geostationary satellite spacings of less than 70°, no interference would be encountered by the radiometer, whether nadir looking or limb sounding.

Since this worst case 3% loss of sensing area would occur only for an inter-satellite system communicating across a 160° arc of the geostationary orbit, and a much reduced interference region would occur from inter-satellite systems operating across less than 150° of the geostationary orbit, this situation* would not occur in practice and therefore it is concluded that limb-sounders can share with geostationary-to-geostationary inter-satellite links.

---

*Refers to hypothetical situations of 1) a polar orbit/side-looking limb sounder and 2) an equatorial orbit with a long track pointing of the limb sounder.

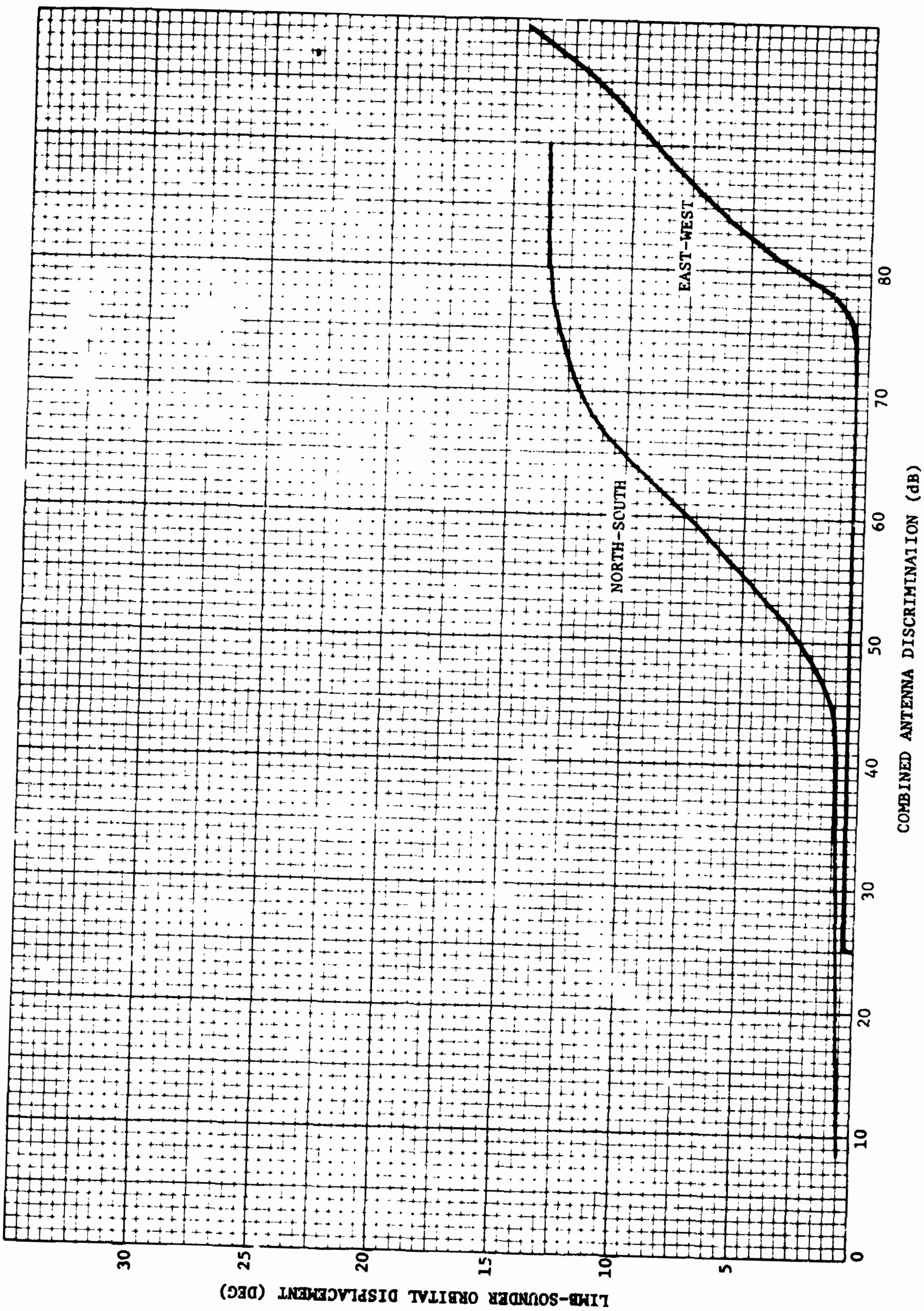



FIGURE 5. AVAILABLE ANTENNA DISCRIMINATION VS. LIMB-SOUNDER ORBITAL DISPLACEMENT

ORIGINAL PAGE IS OF POOR QUALITY

C-4

## 3. GEOSTATIONARY/LOW-ORBIT SATELLITE MODELS

### 3.1 Sytem Model

The communication system parameters for a geostationary/low orbit satellite, a 200 MHz information bandwidth spread over a 2 GHz transmission bandwidth and a required receive C/N of 10 dB, are assumed to be the same as for geostationary-to-geostationary inter-satellite systems (see Section 2.2.). However, because of the more demanding tracking capabilities required for the up- and down-links, wider beamwidth antennas must be utilized.

### 3.2 Transmit Power Requirements

The technical characteristics of geostationary/low orbit links in the Inter-satellite Service have been estimated using an assumed design employing spread spectrum techniques. The design parameters are as follows:

- Required predetection carrier to noise ratio - 10 dB
- Receiver noise - 15 dB
- Transmission bandwidth - 2 GHz
- Geostationary satellite antenna gain - 60 dB(i)
- Low orbit satellite antenna gain - 50 dB(i)

The satellite transmitter power required to permit communications over the link can be computed by the following relationship:

$$P_t = N + 10 \text{ dB} - G_t - A_R + L$$

where: $N$ = receiver noise power

$G_t$ = transmitting antenna gain

$A_R$ = receiving antenna effective

$L$ = spreading loss

For the 54.9 to 55.1 GHz band the required transmitter power is 23.1 dB(W).

The worst case interference geometry would occur if the radiometer, while scanning the earth's limb, received a main beam signal from a geostationary satellite within the radiometer main beam. The interference level in this instance is computed as follows:

| | | |
|---|---|---|
| Transmitted e.i.r.p. | 83.1 dB(W) | |
| Bandwidth conversion factor | - 9.3 dB | (235 MHz/2 GHz) |
| Spreading loss | -163.0 dB($m^{-2}$) | |
| Radiometer antenna effective area (main beam) | + 8.7 dB($m^2$) | |
| Received interference power | - 80.5 dB(W) | |

or 76.5 dB above the interference threshold of -157 dB(W). For nadir-looking radiometers, the interference level would be 2.5 dB below the radiometer interference threshold. This interference would occur only when the geostationary satellite points at the limb.

The probability of occurrence and the duration of this interference situation is very small. For instance, a typical polar orbit adjusted for global repetitive coverage would cause the limb sounder to point to a geostationary satellite only twice per month. The maximum duration of interference in this case would be approximately three minutes and constitute less than 0.8 of one percent of the time. The interference situation therefore will be an infrequent occurrence and the loss of data would be negligible.

A limb sounding radiometer will experience interference whenever its main beam is directed at the sidelobes of the geostationary satellite as seen from the following calculations:

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB/i gain) | 23.1 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Spreading loss | -163.0 dB ($m^{-2}$) |
| Radiometer antenna effective area (main beam) | + 8.7 dB($m^2$) |
| Received interference power | -140.5 dB(W) |

or 16.5 dB above the interference threshold. Although this level does constitute interference to the radiometer, the length of time that interference would be above threshold is of negligible impact to data measurements. For instance, a typical polar orbit adjusted for global repetitive coverage would cause the limb sounder to point at the geostationary

satellite at most twice per month and the duration of interference would be on the order of 20 seconds maximum (.01% of the orbital time). Additionally, the value calculated is conservative in that no account is taken for potential atmospheric attenuation at the earth's limb.

Another potential interference situation is whenever the radiometer passes through the main beam of a geostationary satellite. In this instance, coupling of the signal would be via the side lobe of the radiometer antenna (for both nadir and limb sounding) and the resulting interference level is computed as follows:

| | |
|---|---|
| Transmitted e.i.r.p. | 83.1 dB(W) |
| Bandwidth conversion factor | - 9.3 dB (235 MHz/2 GHz) |
| Spreading loss | -163 dB($m^{-2}$) |
| Radiometer antenna effective area (side lobe) | - 70.3 dB($m^2$) |
| Received interference power | -159.5 dB(W) |

or 2.5 dB below the radiometer interference threshold of -157 dB(W).

Consequently, for the two interference geometries presented above, no significant interference will be experienced by the radiometer due to the geostationary to low orbit link.

## 3.4 Interference Analysis (Low Orbit Satellite Transmitting)

The amount of interference received by the radiometer from a transmitter located on a low orbit spacecraft is highly dependent upon the distance between the two spacecraft, which can vary from tens to thousands of kilometers. The spreading loss therefore may fluctuate as much as 60 to 70 dB.

Since any main beam to main beam couplings are extremely remote, the only significant potential for interference results from side lobe to side lobe coupling.

The following calculation determines the distance required between the two spacecraft in order that side lobe coupling does not cause interference.

| | |
|---|---|
| Transmitted e.i.r.p. (0 dB gain) | 23.1 dB(W) |
| Bandwidth conversion factor | - 10.0 dB (235 MHz/2 GHz) |
| Radiometer antenna effective area (side lobe) | - 56.3 dB($m^2$) |
| Interference threshold | -(-158 dB(W)) |
| Required spreading loss | 114.8 dB($m^{-2}$) |

or a distance of 155 km.

In order for the spacecraft to pass within this distance the orbital altitude of the two spacecraft must be within 155 kilometers. If the two spacecraft are to remain within this distance of each other for a significant amount of time, the basic orbital parameters must be nearly identical. It is highly improbable that two spacecraft would be launched into such similar orbits unless it were a matter of design. Clearly, large areas of interference would not occur.

APPENDIX V

BIBLIOGRAPHY

## SALINITY

Dillinger, A. and J. Paris, 1972, Salinity and temperature analysis program: Project 4699, Houston Aerospace System Division, Lockheed Electronics Company, Inc. Houston, Texas, p. 107.

Droppleman, J. and D. Evans, 1972, Salinity surveys using an airborne microwave radiometer: 4th Ann. Earth Resources Prog. Rev., Vol. I, NASA/JSC.

Paris, J., 1969, Microwave radiometry and its application to marine meteorology and oceanography: Ref. No. 69-IT, Dept. of Oceanography, Texas A & M University, College Station, Texas.

Thomann, G.C., 1973, Remote measurement of salinity in an estuarine environment: Remote Sensing of Environment, v.2, no. 4, pp. 249-259.

Zdanovich, V.G., 1972, Salinity surveys using an airborne microwave radiometer: 8th Internat. Symp. on Remote Sensing of Environment, Ann Arbor, Michigan.

## SEA SURFACE TEMPERATURE

Gurvich, A. ad S. Egorov, 1966: Determination of the surface temperature of the sea from its thermal radio emission: Izv. Atm. and Oceanic Phys., v. 2, pp. 305-307.

Hanson, K., 1972: Remote sensing of the ocean: Remote Sensing of the Troposphere, Chapter 22, USDC-NOAA, Wave Propagation Lab., Boulder, Colorado, p. 56.

Hidy, G., W. Hall, W. Hardy, W. Ho, A. Jones, A. Love, M. VanMelle, H. Wang, and A. Wheeler, 1971: Development of a satellite microwave radiometer to sense the surface temperature of the world's oceans, S-band radiometer: Final Report, Contract No. NAS 1-10106, Space Division, North American Rockwell.

Paris, J., 1969: Microwave radiometry and its application to marine meteorology and oceanography: Ref. No. 69-IT, Dept. Oceanography, Texas A & M University, College Station, Texas.

Stogryn, A., 1967: The apparent temperature of the sea at microwave frequencies: IEE Trans. Ant. Prop., V. 29, pp. 776-782.

## SOIL MOISTURE

Basharinov, A.E., L.F. Borodin, and A.M. Shutko, 1974: "Passive Microwave Sensing of Moist Soils", in Proc. Ninth International Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, 363-367.

Cihlar, J. and F.T. Ulaby, 1975: "Microwave Remote Sensing of Soil Water Content", Univ. of Kansas, CRINC Remote Sensing Laboratory, Tech. Rept. 264-6, Contract NAS 9-14052.

Eagleman, J.R., 1974: Moisture Detection from Skylab. Ninth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, 701-705.

Eagleman, J.R., and F.T. Ulaby, 1974: "Remote Sensing of Soil Moisture by Skylab Radiometer and Scatterometer Sensors", Advances in the Astronautical Science, The Skylab Results, Vol. 31, Part 2, 681.

Eagleman, J.R. and W.C. Liu, 1976: "Remote Sensing of Soil Moisture by a 21-cm Passive Radiometer", J. Geophys. Res., 81, 3660-3666.

Schmugge, T., P. Gloersen, T. Wilheit and F. Geiger, 1974: "Remote Sensing of Soil Moisture with Microwave Radiometers", Journal of Geophysical Research, 79, 317-323.

## SNOW

American Society of Photogrammetry, 1975: Manual of Remote Sensing: Volumes I and II, Falls Church, Virginia.

Barnes, J.C., C.J. Bowley, and D.A. Simmes, 1974: The Application of ERTS Imagery to Mapping Snow Cover in the Western United States, Final Report under Contract NAS 5-21803, Environmental Research and Technology, Inc., Concord, MA, 77 pp.

Barnes, J.C., J.L. Cogan, and M.D. Smallwood, 1975: A Study to Develop Improved Spacecraft Snow Survey Methods Using Skylab/EREP Data: Final Report under Contract NAS 9-13305, Environmental Research and Technology, Inc., Concord, MA, 92 pp.

Barnes, J.C., and C.J. Bowley, 1974: Handbook of Techniques for Satellite Snow Mapping, Report Prepared under Contract NAS 5-21803, Environmental Research and Technology, Inc., Concord, MA, 95 pp.

Committee on Polar Research, 1970: Polar Research, A Survey, National Research Council, National Academy of Sciences, Washington, D. C., 204 pp.

Linlor, W., M. Meier, and J. Smith, 1974: "Microwave Profiling of Snowpack Free-Water Content", Proceedings of Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources, National Academy of Sciences, Washington, pp. 729-736.

Salomenson, V.V., 1974: "Water Resources", in Proceedings of Third ERTS Symposium, Volume II, NASA SP-356, Goddard Space Flight Center, pp. 126-137.

Strong, A.E., E.P. McClain, and D.F. McGinnis, 1971: "Detection of Thawing Snow and Ice Packs through the Combined Use of Visible and Near-Infrared Measurements from Earth Satellites", Monthly Weather Review, 99, (11), pp. 828-830.

Wiesnet, D.R., 1974: "The Role of Satellites in Snow and Ice Measurements," Proceedings of Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources, National Academy of Sciences, Monterey, California, December 2-6, 1973, pp. 447-456.

Wiesnet, D.R., and D.F. McGinnis, 1973: "Hydrologic Applications of the NOAA-2 Very High Resolution Radiometer," Symposium on Remote Sensing and Water Management, Burlington, Ontario, Canada (June).

## SEA STATE

Blanchard, D., 1963: Electrification of the atmosphere by particles from bubbles in the sea: Progress in Oceanography, Vol I, New York, Pergamon Press.

Cardone V., 1969: Specification of the wind field distribution in t. marine boundary layer for wave forecasting: Report TR 69-1, New York, New York Univ., Geophysical Sciences Lab.

Conway, J., 1970: Laser and microwave observations of sea-surface conditions for fetch-limited 17-25 m/s winds: IEEE Trans. Geosci Electronics. v. GE-8, p. 326-336.

Cox, C. and W. Munk, 1954a: Measurement of the roughness of the sea surface from photographs of sun's glitter: Jour. Optical Soc. of America, v. 44, p. 838-850.

Cox, C. and W. Munk, 1954b: Statistics of the sea surface derived from sun glitter: J. Marine Res., v. 13, pp. 198-227.

Droppleman, J., 1970: Apparent microwave emissivity of sea foam: Jour. Geophys. Res., v. 75, pp. 696-698.

Hall, F., 1972: Microwave brightness temperature of a wind blown sea: 4th Annual Earth Resources Program Review, Vol. I, NASA Johnson Space Center, Houston, Texas.

Monahan, E., 1969: Freshwater whitecaps: Jour. Atmos. Sci., v. 26, pp. 1026-1029.

Nordberg, W., J. Conaway, D. Ross, and T. Wilheit, 1971: Measurement of microwave emission from a foam covered, wind driven sea: Jour. Atmos. Sci., v. 28, pp. 429-435.

Ross, D. and V. Cardone, 1972: Observations of oceanic whitecaps for moderate to high wind speeds: 4th Ann. Earth Resource Prog. Rev., NASA Johnson Space Center (formerly Manned Spacecraft Center), Houston, Texas.

Williams, G., Jr., 1969: Microwave radiometry of the ocean and the possibility of marine wind velocity determination from satellite observations: Jour. Geophys. Res., v. 74, pp. 4591-4594.

## SEA ICE

Blinn, J.C. III, 1975: "Microwave Measurements of Ice Thickness", Environmental Research & Technology, Inc., Final Report under JPL Contract No. 953748.

Campbell, W.J., P. Gloersen, W. Nordberg, and T.T. Wilheit, 1973: Dynamics and Morphology of Beaufort Sea Ice Determined from Satellites, Aircraft, and Drifting Stations, NASA Publication X-650-73-194, NASA/GSFC.

Fletcher, J.O., 1966: "Forward", Proc. of the Symposium on the Arctic Heat Budget and Atmospheric Circulation, Memorandum RM-6233-NSF, The RAND Corporation.

Gloersen, P., T. Wilheit, and T. Schmugge, 1972: "Microwave Emission Measurements of Sea Surface Roughness, Soil Moisture, and Sea Ice Structure:, Fourth Annual Earth Resources Progress Review, Vol. i, NASA/JSC, Houston, Texas.

McClain, E.P., 1974: "Some New Satellite Measurements and their Application to Sea Ice Analysis in the Arctic and Antarctic", Proceedings of Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources, National Academy of Sciences, Washington, pp. 457-466.

McClain, E.P. and M.D. Baliles, 1971: "Sea Ice Surveillance from Earth Satellites:, Mariners Weather Log, 15 (1), pp. 1-4.

Meeks, D.C., R.O. Ramseier and W.J. Campbell, 1974: "A Study of Microwave Emission Properties of Sea Ice - AIDJEX 1972", in Proc. Ninth International Symposium on Remote Sensing of Environment, pp. 307-322, Univ. of Michigan, Ann Arbor.

NASA, 1973: US-USSR Bering Sea Expedition Convair-990 Navigational Flight Data, Prepared, Programming Methods, Inc. for the Laboratory for Meteorology and Earth Sciences, Goddard Space Flight Center, NASA, under contract NAS5-11930, Greenbelt, Maryland.

Wilheit, J., J. Blinn, W. Campbell, A. Edgerton, and W. Nordberg, 1971: Aircraft Measurements of Microwave Emission from Arctic Sea Ice, X651-71-417, NASA/GSFC, Greenbelt, Maryland.